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EXTENDING THE SYSTEM DYNAMICS MODEL OF SOFTWARE PROJECT MANAGEMENT TO A MULTIPROJECT ENVIRONMENT

by

Darlene A. Brabant

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Thesis Advisor: Tarek K. Abdel-Hamid

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This tool was expanded to model a multiproject environment in which more than one project is managed. Identification and addition of the variables necessary to reflect manpower decisions resulting in movement between projects and within an organization were effected. This enhancement provided insights into the allocation of resources to projects and into the optimization of the staffing function.

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Extending the System Dynamics Model of Software Project Management to a Multiproject Environment

by

Darlene A. Brabant
Captain, United States Marine Corps
B.A., Davidson College, 1979

Submitted in partial fulfillment of the requirements for the degree of

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March 1990

Author: Darlene A Brabant
Darlene A. Brabant

Approved by: T. Abdel-Hamid
Tarek K. Abdel-Hamid, Thesis Advisor

Magdi Kamel, Second Reader

David R. Whipple, Chairman
Department of Administrative Sciences

ABSTRACT

Increase in the demand for software, coupled with concerns regarding cost overruns and schedule delays in software development lead experts to believe that the United States will be unable to produce the software it needs. In order to improve their performance, software professionals must first understand the development process. The System Dynamics model of software project management provided a tool for the understanding of a single project.

This tool was expanded to model a multiproject environment in which more than one project is managed. Identification and addition of the variables necessary to reflect manpower decisions resulting in movement between projects and within an organization were effected. This enhancement provided insights into the allocation of resources to projects and into the optimization of the staffing function.

TABLE OF CONTENTS

I. INTRODUCTION

A. BACKGROUND

While computer hardware productivity continues to improve, software productivity is unable to "hold its own." [Ref. 1:p. 43] This is true at a time when there is an ever increasing demand for development and implementation of software applications. The demand for software will continue to grow at a huge rate; one estimate places that figure at 25 percent annually [Ref. 2:p. 31].

Increase in the demand for software is not the only problem facing the software industry. Other concerns include software that costs more than it is budgeted for, software that is delivered late or not at all, and software that doesn't meet user requirements. All these considerations lead to the concern that the United States will be "unable to produce the software it needs." [Ref. 2:p. 31]

In order to meet the demand facing the software industry while addressing the concerns listed above, it is necessary that software professionals understand the software development process. Only after this has taken place will economical and timely development of software applications be feasible.

Understanding the software development process is not as simple as it may seem. As Roberts has pointed out [Ref. 3:p. 293], project management techniques are often based on a single feedback loop, much like that illustrated in Figure 1 [Ref. 4:p. 1427].

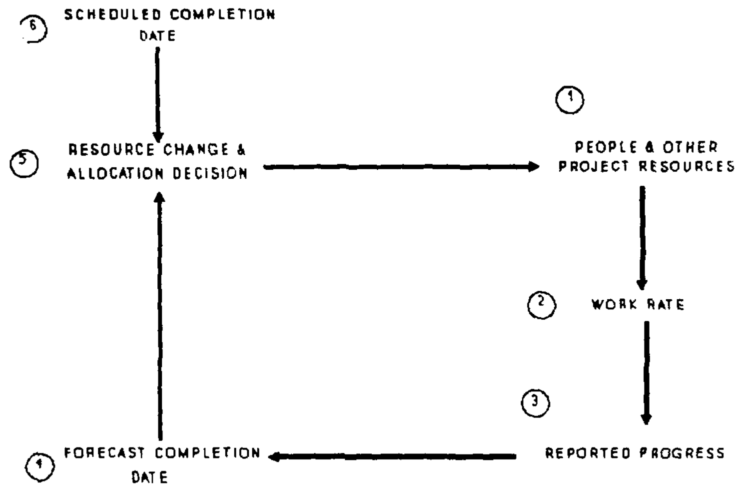


Figure 1. A Model of Software Project Management

Actual software development processes are, however, much more complex and involve more interdependent, interrelated variables [Ref. 4:p. 1427]. A more realistic model of the software development process, illustrating some of these variables and their interdependence, is shown in Figure 2 [Ref. 4:p. 1428]. More importantly, understanding the

behavior of this process and these interrelationships "is complex far beyond the capacity of human intuition." [Ref. 4:p. 1428]

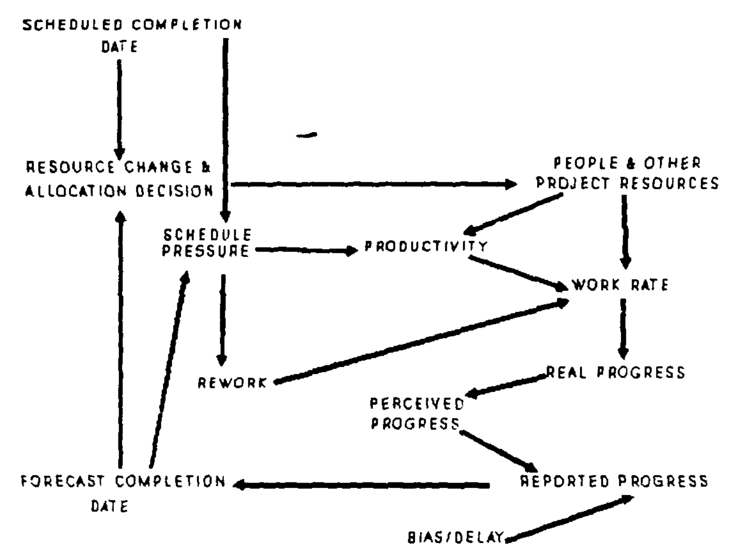


Figure 2. Amendment to the Project Management Model

While understanding a single project is beyond the capability of human beings, understanding multiple projects running in parallel or concurrently is even more difficult. Yet it is in just this situation that many organizations find themselves. As Archibald states, "It is rare to find a project that exists by itself without interaction with other projects." [Ref. 5:p. 59] He continues to emphasize that

the "basic problems result from competition between... projects for resources...." [Ref. 5:p. 59] Most software organizations are in the process of developing many projects at any time; effective management of these projects is not possible without an understanding of how they are interrelated.

B. THESIS OBJECTIVES

The primary objective of this thesis is expansion of the human resource management subsystem of the System Dynamics model of software project management, presented in Reference 4. The model will be described in depth in Chapter II. This expansion is to enable the model to demonstrate the effects of manpower decisions in a multiproject environment. It will allow modelling of an organization through which many projects are being managed at the same time. These projects may have different starting dates, different amounts of resources (time, money), and different characteristics (delivered source instructions).

Through this expansion of the existing model, information can be gleaned in the following areas:

1. Effects of management manpower decisions on the allocation of resources to different projects in a software development arena.
2. Identification of the additional variables necessary to reflect manpower decisions resulting in movement between projects and within an organization.
3. Insights to be gained on optimizing the staffing function in a multiproject environment.

C. METHODOLOGY

Prototyping will be used in developing this thesis. Initially, the redesigned human resource management subsystem will be implemented in an existing smaller model. This will be an iterative process with continuing adaptations being made to the code as analysis of results indicates the necessity for these changes to make the model a more accurate reflection of reality. Once an acceptable design is achieved, it will be incorporated, along with any necessary adaptations, to a more detailed model. A description of this enhanced model can be found in Chapter III. Then experimentation with staffing policies will be conducted; results of these experiments will be presented in Chapter IV.

II. THE SYSTEM DYNAMICS MODEL OF SOFTWARE PROJECT MANAGEMENT

A. SYSTEM DYNAMICS

The software project management model which is to be enhanced is based on the concept of system dynamics. As Roberts states, "System dynamics is the application of feedback control systems principles and techniques to managerial, organizational, and socioeconomic problems." [Ref. 3:p. 3] The philosophy of the system dynamics approach is that the behavior of an organization is a reflection of its structure, including policies and traditions [Ref. 3:p. 4]. Yet another aspect of system dynamics is the idea that one can most effectively view organizations in terms of their flows (such as the flow of people into and out of the workforce) and the cause-and-effect chains which can be traced through these flows [Ref. 3:p. 5].

These organizational relationships are of two types--levels and rates. A level represents accumulations of resources over time of flows or changes that come into and out of that level [Ref. 3:p. 195]. In the software development application of the svstem dynamics approach, one example of a level is the number of people, or workforce level, involved in the development of a project. A rate includes any "flow, decision, action, or behavior that

changes over time as a function of the influences acting upon it." [Ref. 3:p. 19] An example of a rate in the model is that of assimilation rate--the rate at which workers are assimilated into the workforce. Modelling of these organizational relationships is the first step in the application of the system dynamics approach.

The next step for a system dynamics project is to apply computer simulation techniques to the model. These techniques enable the user to understand the complex interrelationships existent in a feedback system. According to Roberts, a feedback system exists whenever an individual takes an action which will later influence other actions he takes [Ref. 3:p. 7]. For example, in software development, a project manager may decide to begin a project with only five programmers. This decision will affect whether the project remains on schedule which will in turn affect whether the project manager needs to hire more programmers. Figure 1 provides an example of a very simplistic feedback loop. Figure 2 portrays a feedback loop which is more realistic and obviously more difficult for a human being to comprehend. It is for this reason that computer simulation is necessary to reflect the interrelationships in the real system.

Dynamo is the computer simulation language in which the software project management model was written. It is a computer program which is capable of executing continuous

simulation models. Dynamo was developed at the Sloan School of Management at M.I.T. in the late 1950's [Ref. 6:p. viii]. According to Roberts, Dynamo is "a major asset to the system dynamics effort." [Ref 3:p. 5]

B. MODEL STRUCTURE AND BEHAVIOR

The System Dynamics model of software project management was developed to aid the software project manager in understanding the software development process and the dynamic behavior of a project. As previously mentioned, the software development process includes many complex, interrelated variables. Understanding and tracing the relationships among these variables is beyond the capability of human intuition [Ref. 7:p. 6]. This model provides the necessary information to allow human beings to view the results of these interrelationships and the effects of the many variables on each other.

It is important to clarify two points. First, the focus of the model is on the aspects of the project that change over time such as workforce level rather than aspects which remain constant, such as programming language. Second, this model was not intended to provide "point-predictions." It is descriptive rather than prescriptive in nature and was designed to be used in understanding relationships rather than predicting them. [Ref. 7:p. 8]

The model integrates the multiple functions of software development to include both management-type functions such

as planning and controlling and software production-type functions such as coding and testing [Ref. 7:p. 6]. A description of how these functions are integrated will be presented later in this chapter.

Finally, the model allows the manager to perform sensitivity analysis by changing the values of variables and viewing the results of these changes. This capability is particularly important when studying feedback systems since they "exhibit behavior that cannot be anticipated by studying the components of the system in isolation." [Ref. 6:p. 1] The results of changing a variable cannot be predicted by the manag-- solely on the basis of the new value of the variable; the model gives the manager the ability to see the overall results of any changes and how those changes affect many variables.

The System Dynamics model of software project management was developed on the basis of interviews of software project managers in five organizations. It comprises four subsystems as depicted in Figure 3 [Ref. 7:p. 8a]. These include the human resource management subsystem, the software production subsystem, the controlling subsystem, and the planning subsystem. Some of the interrelationships among the four subsystems are also illustrated in Figure 3. A brief description of each subsystem follows. A more complete discussion of the model can be found in Reference 4.

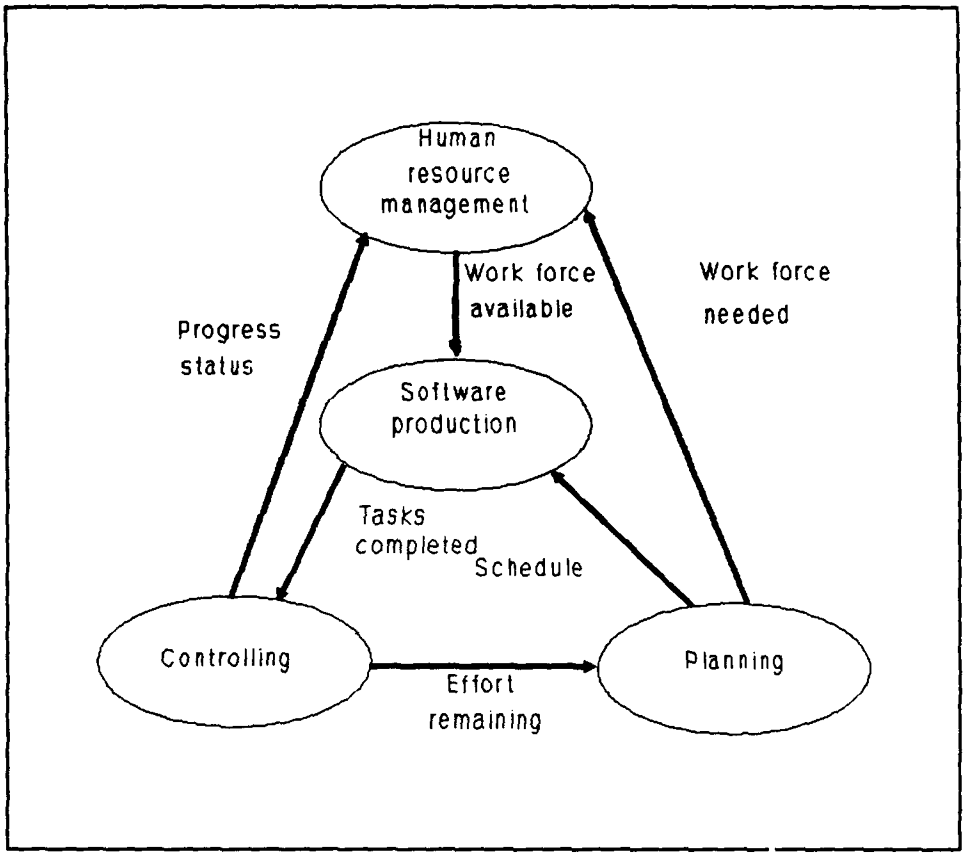


Figure 3. The System Dynamics Model of Software Project Management

1. <u>Human Resource Management Subsystem</u>

The human resource management subsystem models the hiring, training, assimilation, and transfer of the workforce. In this subsystem, a distinction is made between newly hired and experienced workforce, as new team members tend to be less productive than experienced ones. [Ref. 2:p. 102]

The differentiation between new and experienced workers also allows modelling of the training process

involved in assimilating new hires. As veterans train newcomers, this training can reduce the veterans' productivity which will affect the project's progress. [Ref. 2:p. 102]

Several factors influence the project manager's decision regarding workforce size. Amongst these are the scheduled completion date and the workforce stability. Concern over workforce stability leads project managers to attempt to predict the project employment time for perspective employees before they are hired. Generally, the "weight the managers give to stability versus completion date changes as the project progresses." [Ref. 2:p. 102]

This subsystem will be the primary area in which enhancements to the model will be made. Development of the central staffing function necessary to model the transfer of personnel between projects will occur in this subsystem.

2. Software Production Subsystem

The software production subsystem models the development phase, to include design, coding, and testing. It does not include the requirements definition phase nor does it include the operation and maintenance phases.

This subsystem models productivity, defined as potential productivity minus the loss from faulty processes. Potential productivity is the maximum level of productivity that can be reached when a group makes best use of its resources. It is dependent on the nature of the task and

the resources available to the group. "Loss from faulty processes are losses in productivity from things like communication and coordination overhead and low motivation." [Ref. 2:pp. 102-103]

3. Control Subsystem

In all organizations, the decision makers make decisions based on the available information, which is often inaccurate. Factors such as time lag, information flow, and distortion cause perceived conditions to be far different from those actually encountered. [Ref. 2:p. 103]

Progress rate is one example of a variable in the model which is difficult to measure during the project. Determination of a quantifiable way in which to measure progress is one of the greatest roadblocks to accurate measurement. Often when a programmer is asked to provide an estimate of the amount of progress, he will divide the amount of time he has spent on the project by the amount of time budgeted. The realization that his estimate is wrong will occur only towards the end of the project. [Ref. 2:p. 103]

This type of progress measurement causes status reporting to be an echo of original estimates, often grossly misstated. As the project progresses into its final phases, accomplishments tend to become more visible and project members are better able to report how productive they have been. [Ref. 2:p. 103]

4. Planning Subsystem

In the planning subsystem, initial project estimates are made at the beginning of the project for various factors such as completion time, original staffing levels, and man-days required to complete the project. These estimates are revised throughout the project's life based on feedback from other subsystems.

For example, if a project is perceived to be behind schedule, plans can be made to add more people, extend the project's schedule or do some of both. These types of decisions are motivated by variables that change dynamically through the project's lifecycle. One illustration of this occurrence has to do with staffing level. Often, management will respond to a project being delayed in its early stages by increasing the workforce. However, as time passes and it becomes later in the project's lifecycle, management becomes more and more reluctant to change the workforce. This is due to the realization that the time doesn't exist, prior to the necessary completion date, to assimilate and train these new people. [Ref. 4:p. 1431]

C. SUMMARY

In this chapter, a brief, high-level explanation of the System Dynamics model of software project management has been presented. For the interested reader, a more detailed description of the model can be found in Reference 4. The explanation presented in this chapter provides a basis for

understanding of the extension of the model to a multiproject environment, the purpose of this thesis. This extension is described in the next chapter.

III. EXTENSIONS TO MODEL A MULTIPROJECT ENVIRONMENT

A. EXISTING MODEL

The System Dynamics model as described in the previous chapter allows simulation of one project at a time. Though this enables project managers and others involved in software development to understand the dynamics of this one project, it ignores the dynamics of situations involving two or more projects. Software organizations are often, if not always, involved in the development of more than one project or of a project with more than one component. People are transferred between projects or components as well as being hired and fired. Many variables affect management's decisions regarding when and how these workforce changes should take place. Extension of the System Dynamics model to enable the model to demonstrate the effects of these manpower decisions in a multiproject environment is the primary objective of this thesis.

This extension affected primarily the human resource management subsystem as the movement of people with regards to the workforce was the point of interest. In order to grasp the changes made, one must first be somewhat familiar with the subsystem as it existed prior to enhancement. Recall that the human resource management subsystem is one of four interrelated subsystems making up the System

Dynamics model. This relationship is pictured in Figure 4 [Ref. 7:p. 8a].

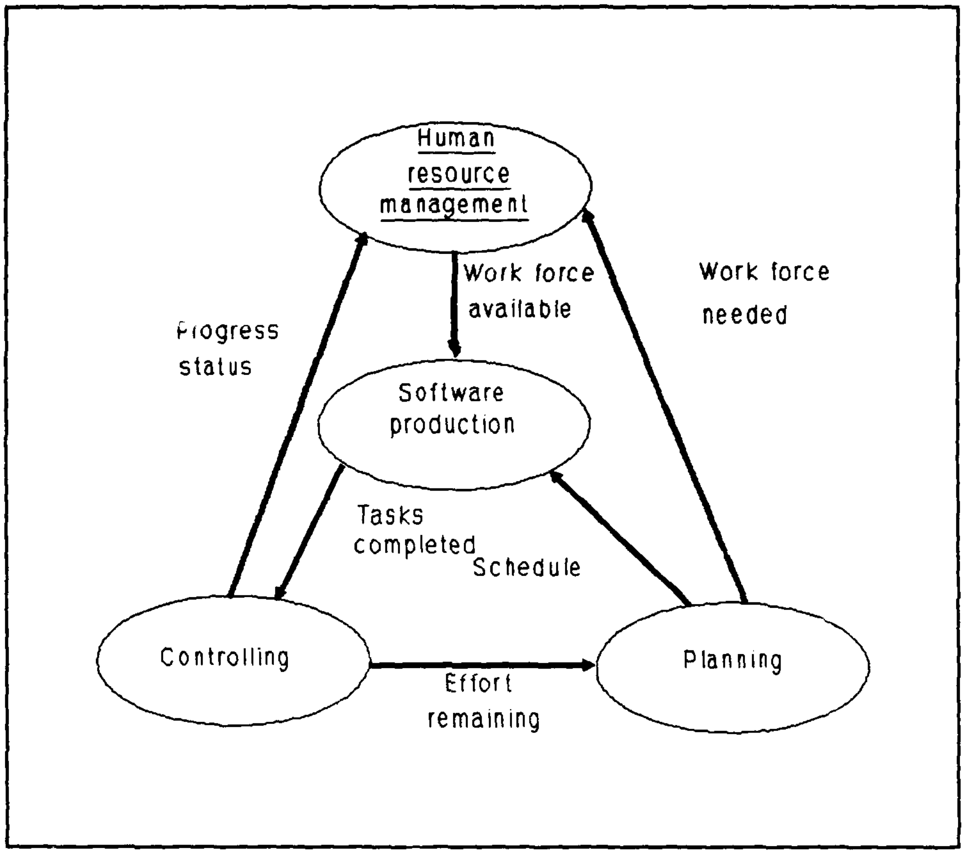


Figure 4. The System Dynamics Model of Software Project Management

The human resource management subsystem models the movement of people into and out of the workforce. It also models the training and assimilation of the workforce. [Ref. 7:p. 102] Figure 5 illustrates the design of the subsystem prior to its extension [Ref. 7:p. 8b]. A more complete description of this subsystem and the model as a whole can be found in Reference 4.

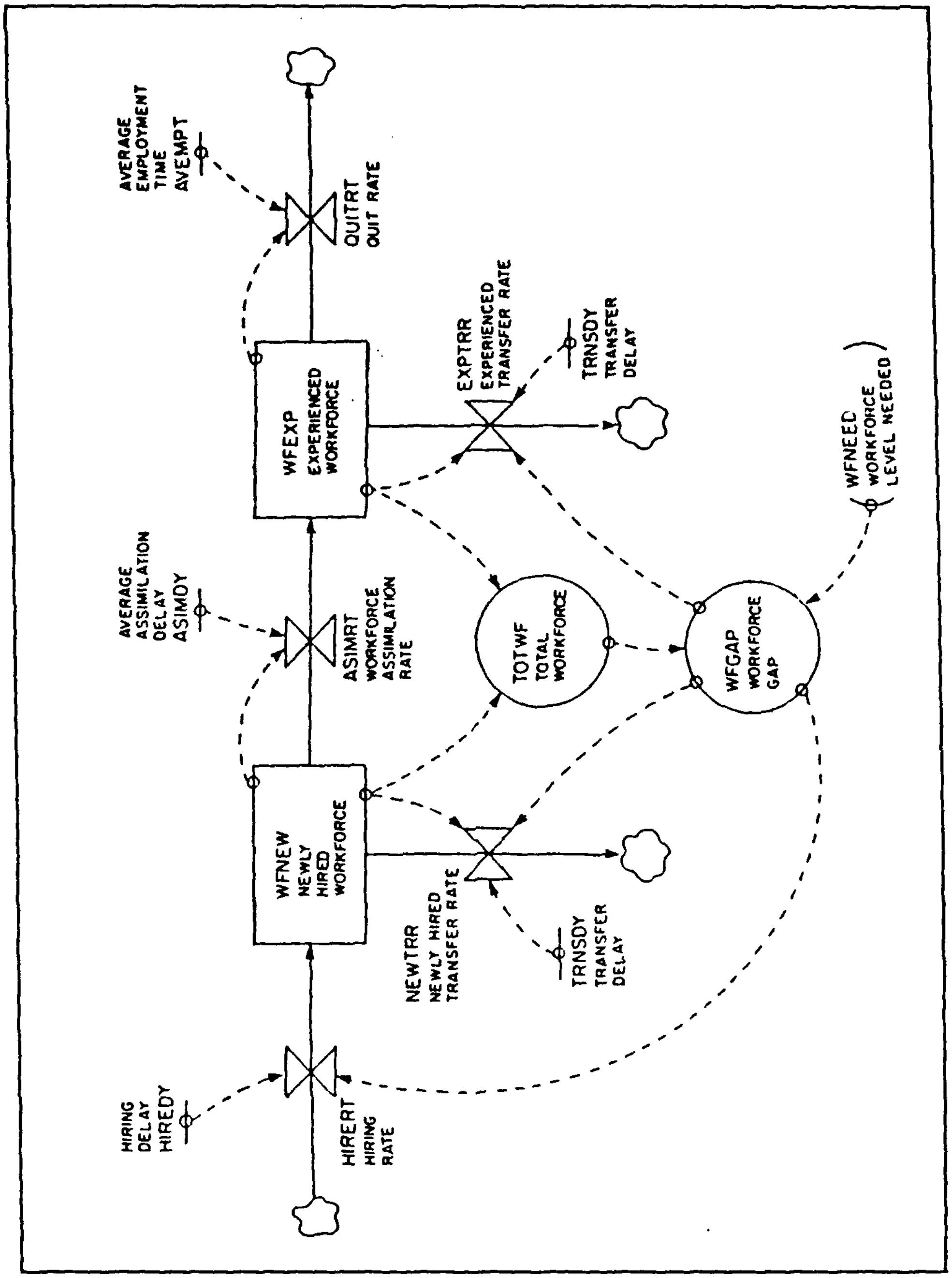
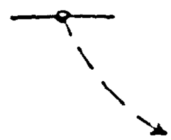


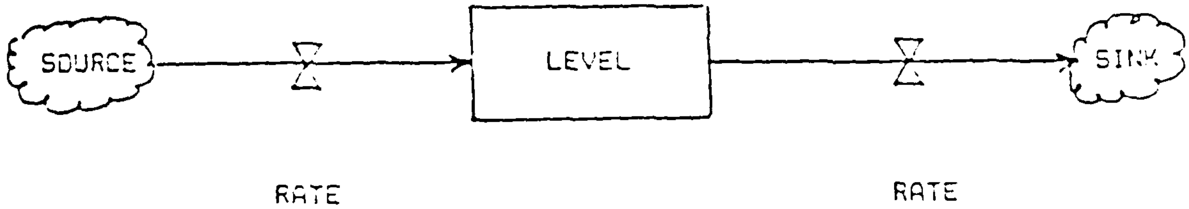
Figure 5. The Human Resource Management Subsystem

The schematic conventions used in Figure 5 are the standard conventions used in system dynamics models.

Constants, whose values will not change over the course of the simulation, are indicated by the symbol shown below:



Variables, as discussed in Chapter II, include levels and rates. These are represented as shown below:



The cloud-like symbols represent sources and sinks which indicate where resources come from and go as they flow into and out of levels. "For example, for a level of workforce these symbols represent where people come from when hired and where they go when leaving the project." [Ref. 7:p. 9]

Referring back to Figure 5, one can see these symbols used to indicate the relationships between the variables in the human resource management subsystem. For instance, the source (the cloud-like symbol) on the left of the figure represents people available to be hired. They are hired by the organization at a certain rate (HIRERT), i.e., people per day. This rate is influenced by the delay in hiring

(HIREDY) and how many people need to be hired (WFGAP). Once hired, these people become part of the newly hired workforce (WFNEW). By tracing Figure 5 in this manner, the relationship between the variables in the existing human resource management subsystem becomes evident.

B. MODEL EXTENSIONS

Three changes were made to the existing model to enable simulation of a multiproject environment. The first and second of these did not involve the human resource management subsystem alone but rather affected the entire model. The first change was to modify all applicable variables so that they represented arrays. The addition of arrays enabled appropriate variables to be applied to both projects (the completed extension to the model permits simulation of two projects at the same time). This capability reduced greatly the need for redundant program code.

The second change involved inclusion of a variable which would allow independent modelling of the two projects. This variable, start date (STRTDT), is aptly named in that it represents the time at which each project begins development. It can be changed to simulate different projects starting at different times relative to each other. "What if" analysis can be performed by making changes to this variable. This analysis can help the manager to

determine optimum degrees of overlap necessary to attain certain goals, such as minimizing costs or project duration.

The third change, the most major one, was made to the human resource management subsystem. This change centered on addition of a centralized staff-coupling sector to be used in simulating the transfer of people between projects. A diagram of this concept is shown in Figure 6.

The change required identification and introduction of many variables to accurately model the numerous factors involved in a manager's decision to change his workforce through intraorganization transfers. The high level design of the model is shown in Figure 7. Note that this design illustrates only those factors involved in transferring workforce from project two to project one. Transfers effected in the other direction require equivalent variables. A key to the translation of the variable names can be found in Figure 8; this key is also applicable to the variables identified in Figures 9 and 10.

C. DESCRIPTION OF MULTIPROJECT ENVIRONMENT

As stated earlier, the major modification to the existing model was addition of the changes necessary to simulate transfers between projects. The remainder of this chapter will be devoted to a description of the environment in which the decision to use transferred workers is made and how these transfers are effected. To enhance clarity in this discussion, only the situation in which project one has

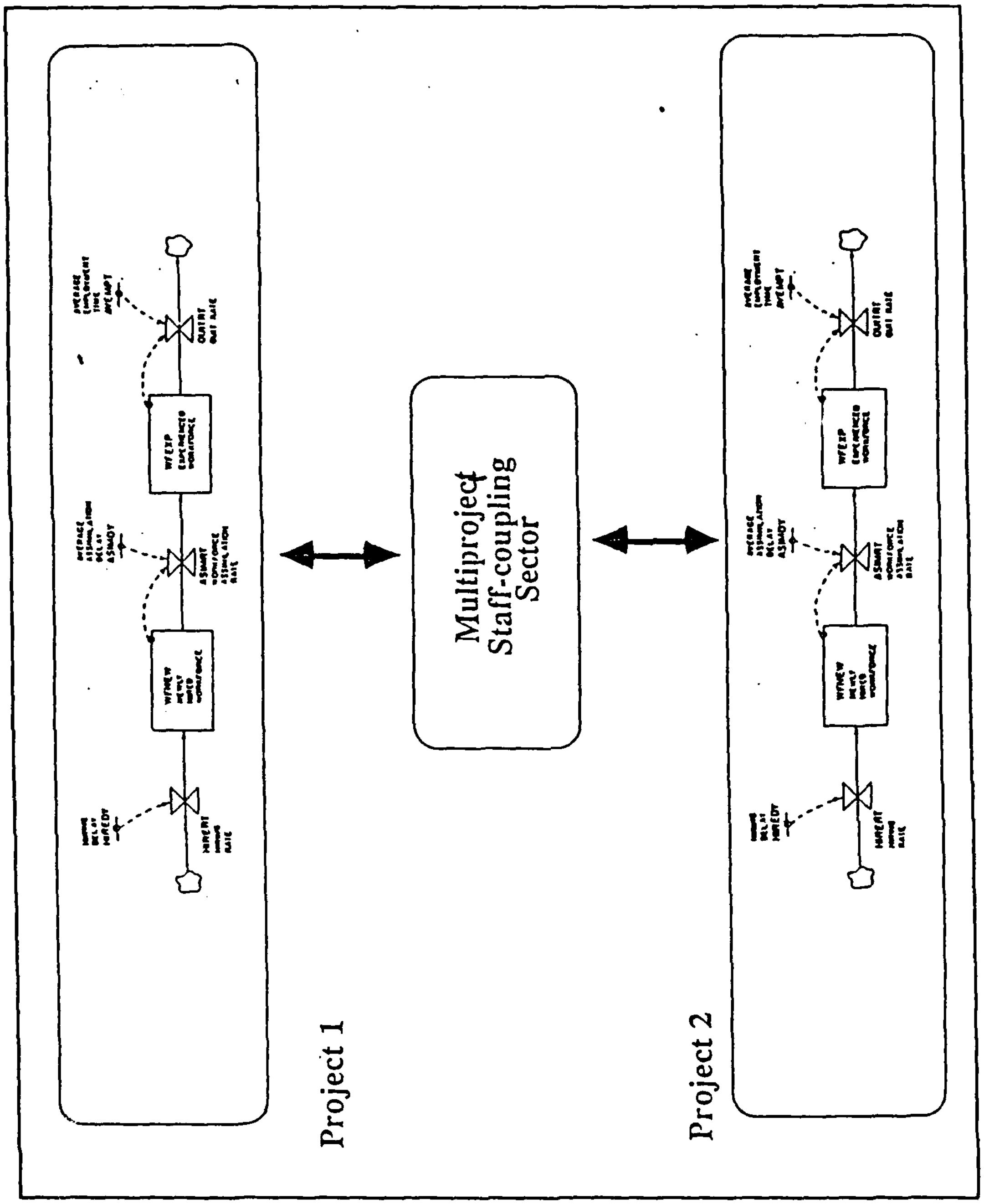


Figure 6. The Multiproject Staff-Coupling Sector

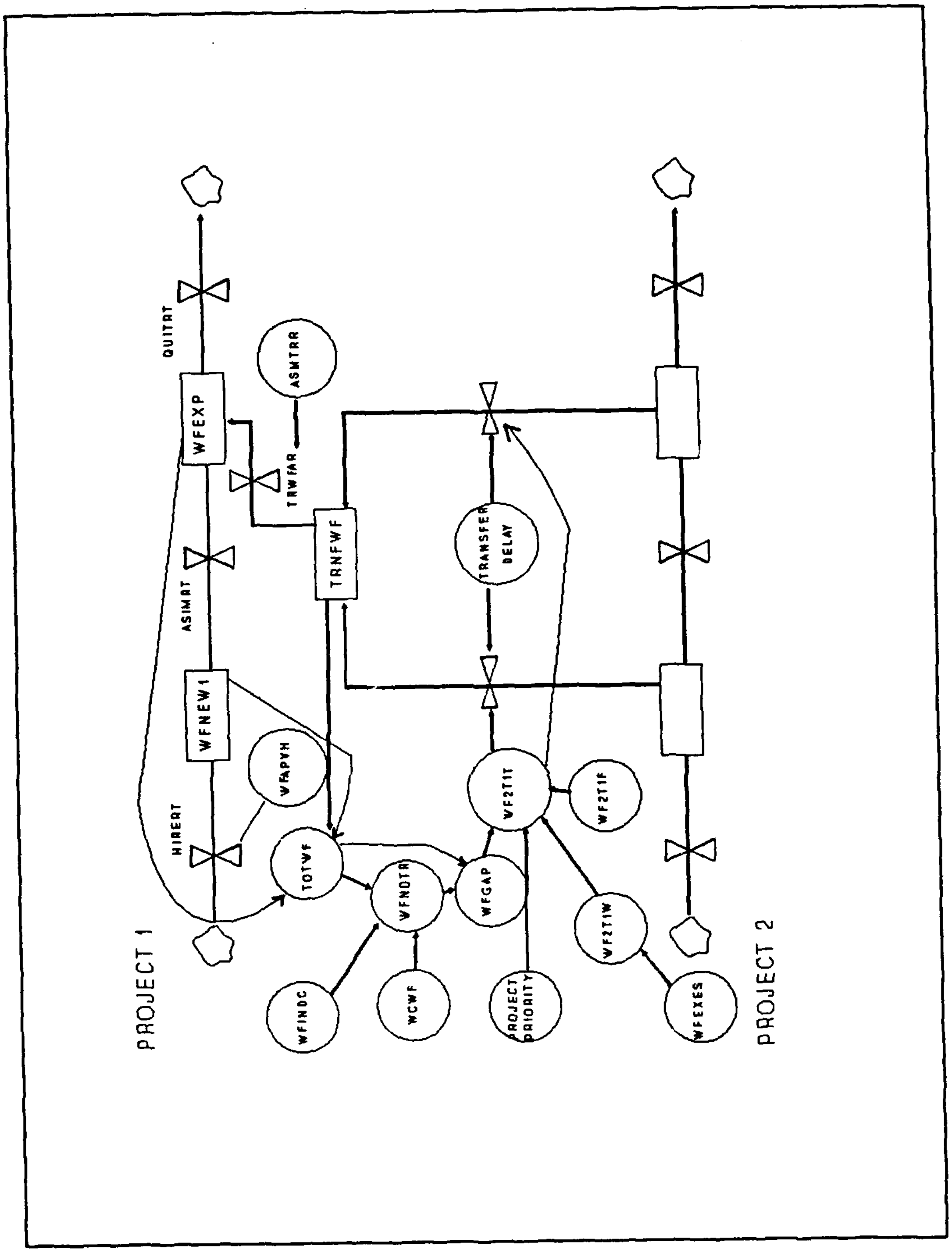


Figure 7. Design of the Multiproject Staff-Coupling Sector

VARIABLE KEY

ASIMRT=ASSIMILATION RATE OF NEW EMPLOYEES (PEOPLE/DAY)
ASMTRP=ASSIMILATION DELAY OF TRANSFERRED PEOPLE (DAYS)
CEILHR=CEILING ON HIRING FOR PROJECT 1 (PEOPLE)
HIRERT=HIRING RATE (PEOPLE/DAY)
MNHRXW=MOST NEW HIREES PER EXPERIENCED STAFF (MEN/MEN)
MX2T1F=MAXIMUM WORKFORCE THAT CAN BE FORCED TO TRANSFER FROM PROJECT2 TO PROJECT 1 (PEOPLE)
PROJECT PRIORITY=DETERMINATION OF WHETHER ONE PROJECT HAS PRIORITY OVER ANOTHER
QUITRT=EXPERIENCED PEOPLE QUIT RATE (PEOPLE/DAY)
RLS2T1=WORKFORCE TO BE RELEASED AFTER PROJECT 2'S COMPLETION THAT PROJECT 1 CAN RELY ON AND AFFORD TO WAIT FOR (PEOPLE
TOTWF= TOTAL WORKFORCE LEVEL (PEOPLE)
TRANSFER DELAY=DELAY REQUIRED UNTIL TRANSFER IS AFFECTED (DAYS)
TRNFWF=TRANSFERRED PEOPLE FROM PROJECT 2 TO PROJECT 1 (PEOPLE)
TRWFAR=TRANSFERRED WORKFORCE ASSIMILATION RATE INTO PROJECT 1'S WORKFORCE (PEOPLE/DAY)
WCWF= WILLINGNESS TO CHANGE THE WORKFORCE
WF2T11=MAXIMUM WORKFORCE WE CAN FORCE TRANSFER FROM PROJECT 2 TO PROJECT 1 AS DETERMINED BY MANAGEMENT POLICY (PEOPLE)
WF2T12=WORKFORCE WE CAN TRANSFER FROM PROJECT 2 TO PROJECT 1 WHEN WE TAKE INTO CONSIDERATION WILLINGNESS TO REPLENISH/DELAY PROJECT2
WF2T1F=WORKFORCE THAT WILL BE FORCIBLY TRANSFERRED FROM PROJECT 2 TO PROJECT 1 (PEOPLE)
WF2T1T=TOTAL WORKFORCE THAT WILL BE TRANSFERRED FROM PROJECT 2 TO PROJECT 1 (PEOPLE)
WF2T1W=WORKFORCE TRANSFERRED FROM PROJECT 2 TO PROJECT 1 WILLINGLY (PEOPLE)
WFAPVH=WORKFORCE APPROVED TO HIRE (PEOPLE)
WFARG= WORKFORCE ARRANGED FOR. IT EQUALS WORKFORCE + WORKFORCE TO BE TRANSFERRED TO PROJECT 1 MINUS WORKFORCE TO BE TRANSFERRED OUT
WFEXCS=WORKFORCE EXCESS. IT EQUALS WORKFORCE WILLING TO TRANSFER TO OTHER PROJECT (PEOPLE)
WFEXP= EXPERIENCED WORKFORCE (PEOPLE)
WFGAP= WORKFORCE THAT NEEDS TO BE TRANSFERRED FROM OTHER PROJECT (PEOPLE)
WFINDC=INDICATED WORKFORCE (PEOPLE)
WFNDHR=WORKFORCE NEEDED IF PEOPLE WILL BE HIRED (PEOPLE)
WFNDTR=WORKFORCE LEVEL NEEDED ASSUMING TRANSFERS (PEOPLE)
WFNEW1=NEW WORKFORCE (PEOPLE)
WFOUT= WORKFORCE DEFINITELY NEEDED TO BE HIRED FROM OUTSIDE (PEOPLE)
WFSHR= WORKFORCE SOUGHT TO HIRE (PEOPLE)
WN2T1F=WORKFORCE NEEDED TO BE TRANSFERRED BY FORCE FROM PROJECT 2 TO PROJECT 1 (PEOPLE)

Figure 8. Variable Key

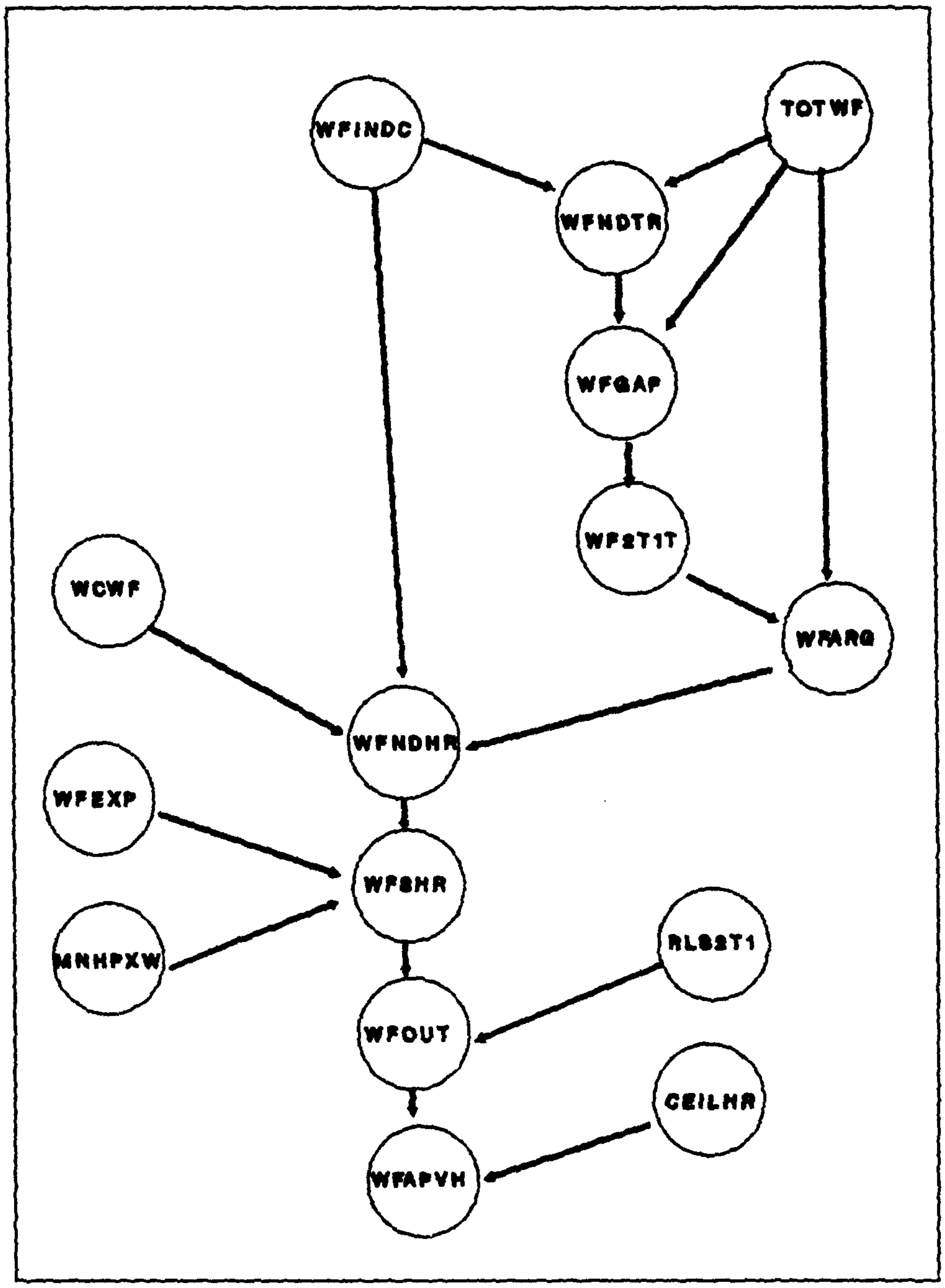


Figure 9. Decomposition of WFNDTR

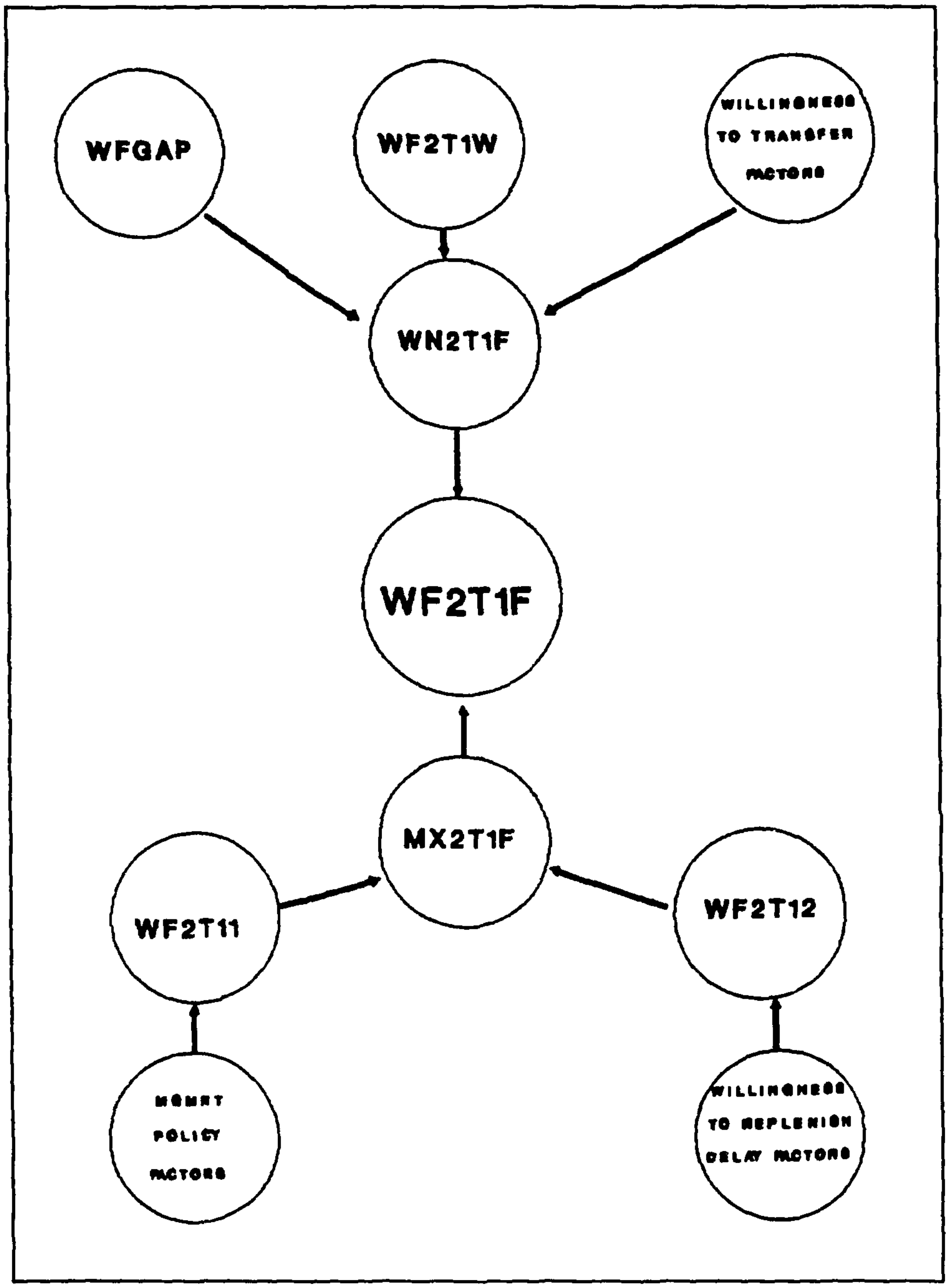


Figure 10. Decomposition of WF2T1F

priority and therefore receives transfers from project two will be described.

First, the manager will determine the total number of workers needed (WFINDC) by ascertaining the scope of the project (man-days required to complete the project as it is estimated). He'll then compare this number to the total workforce (TOTWF) on hand to determine the gap in the workforce (WFGAP). Since transferred workers tend to be more productive and require less assimilation time than their newly hired counterparts, most managers would prefer to meet the gap between what is needed and what is on hand through transfer. This determination of the need for transfers is a continuing process throughout the life of the project as the manager continually updates his estimates of project size and how much of the project is completed. Returning to Figure 7, one can see that it is through this transferring process that the two projects interact. Once the manager has determined the amount of workforce that he needs to have transferred to his project, there are two ways in which these transfers can be affected.

First, these transferees may be people who are transferred willingly (WF2T1W), meaning management in project two acknowledges that they have more than enough people to get the job done. These "willing" transfers are, in fact, recognized as excess workforce (WFEXES) as shown in Figure 7. The workforce which is in excess will be

willingly transferred but this may not meet the needs of project one. The manager then realizes the number of individuals he needs to transfer by force (WN2T1F). This "forced" transferring will occur when the overall organizational goals can best be met through these transfers.

Figure 10 presents the factors involved in determining what amount of the workforce will be transferred by force (WF2T1F). Two factors influence this determination--these factors are management policy and willingness to replenish or delay the other project.

The first item (WF2T11) which influences forced transfers is management policy. This policy is, in turn, determined with regard to two considerations. One consideration is the willingness of project one to force transfers from project two. In the early phases of project development, project one will be more apt to hire from the outside and not disrupt the other project through forced transfer. This is due to reluctance to force transfers from the other project when it is building its "core" team (i.e., in the early stages of the project). The second consideration influencing management policy is attention given to the cumulative number of "recent" transfers as the more recently transfers have occurred in noticeable numbers the less apt the losing manager is to give up yet more people.

The other item (WF2T12) influencing forced transfers is regard for the willingness to replenish or delay the other project. The ability to replenish project two affects the number of forced transfers which take place. If the organization has a workforce ceiling and it is close to that ceiling, there will be more reluctance to replenish project two which will in turn lead to fewer forced transfers. The amount of delay which can be afforded also affects the number of transfers which take place. This delay is a function of the maximum tolerable completion date of the project--the "drop dead" time for completion. The minimum tolerable workforce with which project two can continue development is based on this delay. Forced transfers will not drive the workforce below this number.

The amount of workforce which will be transferred willingly (WF2T1W) combined with the number that can be transferred by force (WF2T1F) constitute the total workforce that will be transferred from project two to project one (WF2T1T). This relationship is shown in Figure 10. The number of individuals who make up the to-be-transferred force combined with the original workforce are then considered to be "arranged for" (WFARG) as shown in Figure 9. Prior to the transfer being achieved, however, a transfer delay is incurred as preparation is made for the transfer both by project two and by the individual. Once the transfer is complete a period of assimilation ensues.

Though individuals transferred (TRNFWF) require some assimilation time (TRWFAR), their rate of assimilation into the gaining project is less than that for newly hired workers. This is attributable to their understanding of the organizational environment and their experience with the organization's policies and standards. Additionally, if the two projects are components of a larger project, the transferred workforce is at least somewhat familiar with that overall project--a familiarity which contributes to their faster assimilation into the workforce. As members of the transferred workforce are assimilated into the new project, they become part of the experienced workforce (WFEXP).

Note that if two projects are running in parallel, transfers will occur only in the direction of the project which has higher priority (PROJECT PRIORITY) until that project completes. This priority status may be exogenously determined by organizational management as, for instance, a result of contract requirements. In the situation being described in this chapter, project one has been exogenously determined to have priority. Also possible is determination of a project's priority based on its proximity to completion relative to the other project. It would be foolish to transfer people out of a project which, due to either of the reasons mentioned above, had been designated as having high priority.

Having determined the workforce arranged for, the manager must once again appraise his workforce situation and determine if he still needs to hire. He will do this by comparing the workforce he needs (WFINDC) to the workforce to which he has access (WFARG). The difference between these two is the gap which the manager must attempt to close by hiring (WFNDHR). Figure 9 shows the relationships between the variables which influence the acquisition of the entire workforce, both through transfer and through hiring. Though the manager may, as far as the numbers are concerned, need to hire a certain number of workers, other considerations come into play. The willingness of management to hire new workers (WCWF) will affect the number actually sought to be hired (WFSHR). Reluctance to hire new workers (WFNEW1) may be due to the nearness of completion of the project--a manager will be less willing to hire a new team member the closer the project gets to completion as there may not be time to assimilate that member. Another consideration managers take into account is the ratio between new and experienced workers (MNHPXW). The productivity of experienced workers (WFEXP) will decline as they take the time and effort to train and socially assimilate their new workers. Aware of this phenomenon, managers will limit this ratio and will hire only in numbers compatible with their productivity needs.

Having calculated the number of workers sought to hire, the manager will once again look at the other project for a possible source of employees. He makes an informed decision regarding the number of individuals to be released upon the other project's completion on which he can rely and for which he can afford to wait (RLS2T1). Since these individuals will be released upon completion of the project, the management policy (WF2T11) and willingness to replenish or delay (WF2T12) factors which affected transfer considerations will not come into play here.

This number (RLS2T1) subtracted from the workforce sought to hire (WFSHR) gives the manager a final figure of the workforce needed to be acquired by hiring (WFOUT). Before these people are actually hired, however, the manager needs to ensure he is following organizational policy with regard to any ceiling on the workforce (CEILHR). Regardless of the number of individuals needed, the organizational ceiling and how that ceiling will be allocated amongst projects will be the final determinants of how many can be hired (WFAPVH). If the manager finds he is unable to get the people he needs, he may need to work the people he has harder or extend the schedule, or both.

Returning to Figure 7, one can see that the workforce which has been approved to hire (WFAPVH) will increase the number of employees in the new workforce (WFNEW1) as they are hired (HIRERT). This number in turn increases the total

workforce (TOTWF) of that project. Once again, and throughout the life of the project, the manager will compare this figure to what he needs (WFINDC) and the cycle of filling the workforce gap will begin anew. It is this sort of cause-and-effect chain which makes the system dynamics approach so appropriate for the software project management world, especially that of multiproject organizations.

The changes described above were incorporated into the existing System Dynamics model of software project management. Addition of the staff-coupling sector, the start date variable and arrays enabled modelling of a multiproject environment. Simulations were run with this new model in an attempt to replicate changes managers might make or contemplate in their management policies. The results of these simulations are presented in Chapter IV.

IV. EXPERIMENT RESULTS

A. EXPERIMENTAL ENVIRONMENT

The System Dynamics model of software project management was written in Dynamo, a computer simulation language which is described in Chapter II. The variables necessary to model a multiproject environment, identified in Chapter III, were incorporated into this Dynamo program. This program, run on a personal computer, provided the vehicle for the conduct of the experiments presented in this chapter.

B. DESCRIPTION OF EXPERIMENTS

After implementation of the changes made to the System Dynamics model of software project management, several experiments were conducted by running simulations. These experiments were conducted using the characteristics of an actual software project. This project, NASA's DE-A project, was conducted at Goddard Space Flight Center. The requirements for the project were to design, implement, and test a software system for processing telemetry data and providing attitude determination and control for the DE-A satellite. The project's size was 24,000 delivered source instructions. This size was initially underestimated by 35 percent. The initial estimates of cost and schedule were 1100 man-days and 320 days, respectively. The actual

results were a cost of 2200 man-days and a schedule of 380 days. [Ref. 4:p. 1432]

In the multiproject environment present in the extended model, these statistics were given to both projects. In most of the simulations the nominal ceiling on the total workforce (NCLTWF) was set to a default value of 30 (exceptions are noted in the text). This condition enabled simulations to be run which showed the effect of manpower constraints. Results of a single project restricted in this manner are a cost of 1909.5 days and a schedule of 398 days. In this case of a single project, the nominal ceiling on the total workforce is 15 (one-half that for the two-project simulations). This constraint was not in effect in the actual DE-A project. Its addition does not affect the fact that the experiments were run with two identical projects both of which were in distress as they were initially underestimated. The results of the experiments will be presented in this chapter. Prior to this, however, an explanation of how the experiments were structured is necessary.

Three sets of experiments were conducted. All three provide a glimpse at the capability for sensitivity analysis that this model provides the software project manager. The first of these involved running simulations to determine the optimal degree of overlap to minimize cost in seven different situations. The second set of experiments

consisted of simulations run based on an optimal degree of overlap when the project starting first had priority. In this case results from 13 simulations, each with a different independent variable, are presented. The third set of experiments consisted of simulations run based on an optimal degree of overlap when the project starting last had priority. Again, results from 13 simulations, each with a different independent variable, are presented. A more detailed description of each experiment precedes the presentation of the results peculiar to that experiment.

C. EXPERIMENT SET ONE

In the first set of experiments, simulations were run to determine the optimal degree of overlap between two projects necessary to minimize costs of the combined projects. In the first five cases, the priority was set dynamically (PRTYSW = 0)--that is, the project whose indicated completion date is farthest from its scheduled completion date would be the project which would receive transfers from the other as it is perceived to be in greater distress. As time progresses the project having priority will change as one project "gains" on the other due to the advantage of receiving transfers.

1. Baseline

Figure 11 shows the results of tests run to determine the optimum overlap required to minimize costs when dynamic priority is used. In this simulation, as in

all others in this experiment set (with the exception of the two simulations in which workforce ceiling was changed), the nominal ceiling on the workforce has the value of 30. Since Figure 11 is identical in format to the others in this section, a brief explanation of it is appropriate.

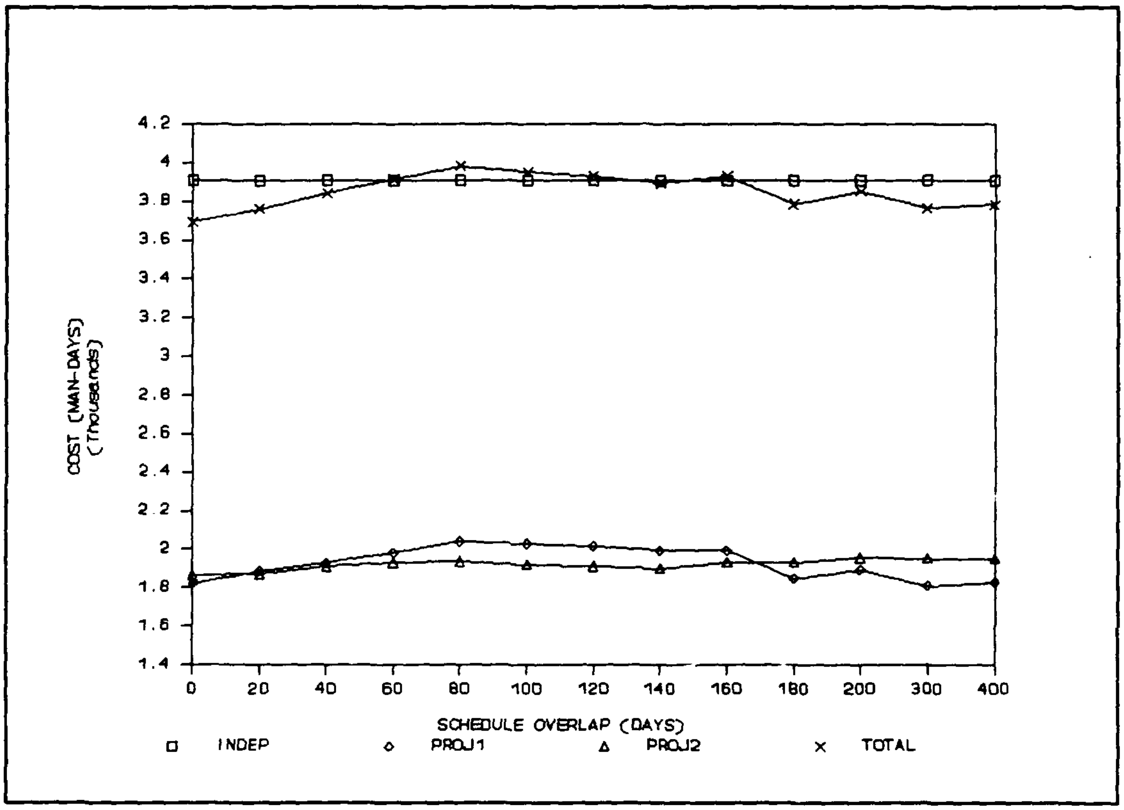


Figure 11. Overlap Results--Baseline

There are four lines of results shown on this figure. The first, "INDEP," indicates the combined cost of two projects run in parallel with no interaction; they are, in other words, independent of each other. No transfers occur between projects. This line is given as a point of

comparison between independent projects and projects developed in a multiproject environment in which human resources are shared.

The second line, "PROJ1," indicates the cost for project one at each point of overlap. Note that for the five simulations run with dynamic priority (this and the next four), project one was always the project to start last. For instance, the number 20 on the X-axis indicates that project one started at time 20 and project two started at time zero. Only when the schedule overlap is zero do the projects start together.

The third line, "PROJ2," indicates the cost of project two at each degree of overlap. Recall that project two is always the project to start first.

The last line, "TOTAL," indicates the combined cost of both projects for each degree of overlap. This line provides the major point of interest as a manager trying to minimize overall costs would focus on this information. It is important to recognize that determination of which project starts first (in this case, project two) does not skew the results when the priority is dynamically set, as it is in five of these experiments. If project one had been chosen to start first, its costs would mirror those of project two in the current results and vice-versa. The total costs would remain unchanged.

The final area of attention with regard to Figure 11 is the choice of 400 as the stopping point for the simulations. The project starting first will complete at time 398, the same time as if it were running in a single project environment. This is because it cannot receive transfers from a project which hasn't started yet. It would appear, then, that the simulations run with one project starting at time 400 would be in fact nothing more than the simulation of two independent projects as the projects seem to have no chance to overlap. In reality, however, even though one project completes at time 398, there is still workforce available to be transferred to the other project as it begins at time 400. This is due to the fact that when a project "ends" there are still things to be taken care of to "wrap" that project up. Individuals still on hand during this time are available for transfer to the other project. The results of this experiment show that the optimal degree of overlap occurs when the projects start at the same time. This is shown in the summary results in the appendix.

2. Transfer Productivity

In the second simulation of this experiment set, the variables changed were the variables which affect the nominal productivity of experienced people (NPPRWT) and transfer delay (TRNSDY). By increasing NPPRWT (from zero to .5) and decreasing TRNSDY (from ten to five), the scene set is one in which transferred people are more productive. As

stated earlier, the priority is set dynamically in this simulation. The results of the tests run to determine the optimum degree of overlap to minimize cost are shown in Figure 12. The summary of the results is contained in the appendix. They show that the optimal degree of overlap occurs when the projects start at the same time.

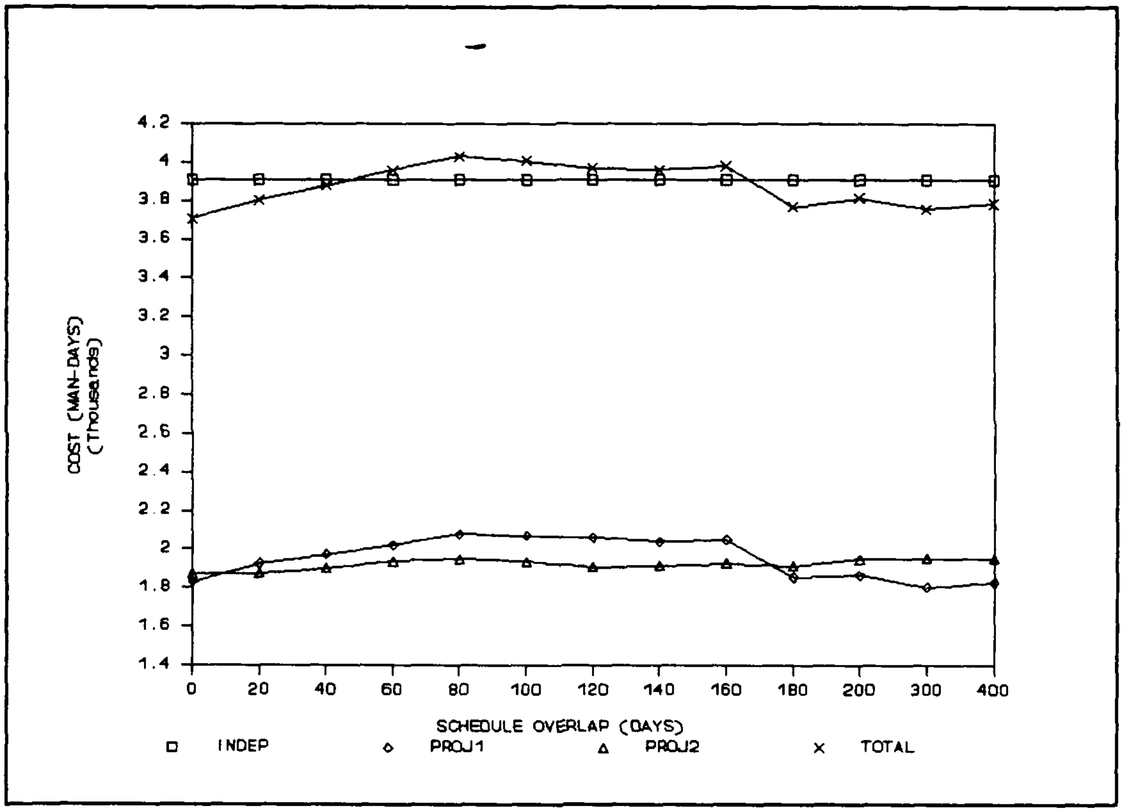


Figure 12. Overlap Results--Transfer Productivity

3. Workforce Ceiling

In this set of simulations, the ceiling on the organizational workforce was decreased from the default value of 30 to 20. The priority is, once again, determined

dynamically. The results of the efforts to determine the optimum degree of overlap to minimize costs under these conditions are shown in Figure 13. The summary results are presented in the appendix. They show that the optimal overlap occurs under these conditions when one project starts 400 days after the other.

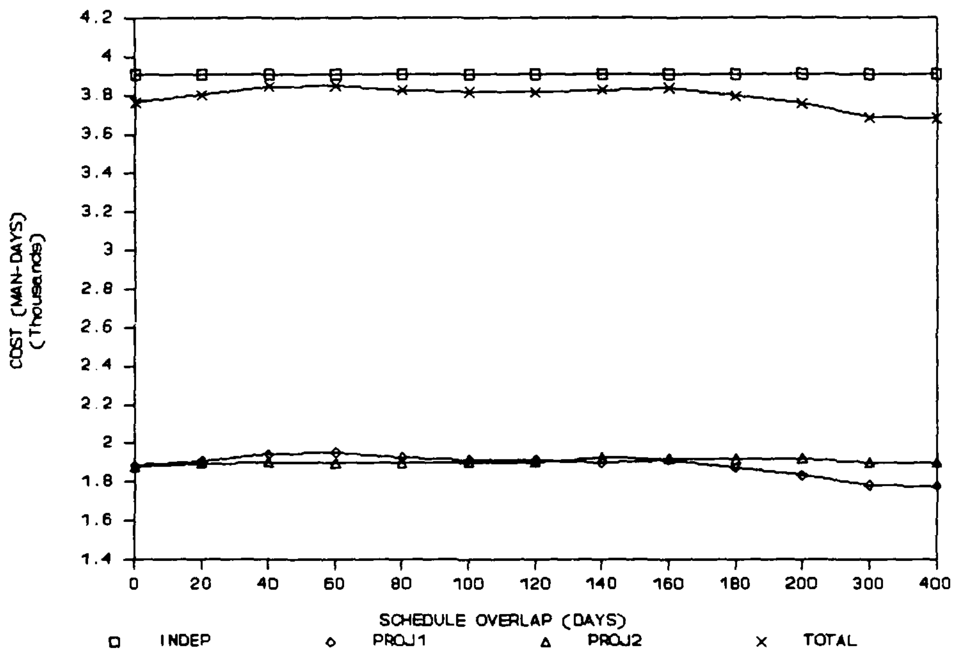


Figure 13. Overlap Results--Workforce Ceiling

4. Workforce Ceiling and Allocation

In this scenario, the conditions were the same as in the third, above, with the addition of one other change. The allocation of the workforce ceiling was set such that

the project with priority could employ up to the ceiling on workforce for the entire organization, leaving the other project with no pool from which to acquire additional workforce (POLCY1 = 0). Normally, the ceiling is allocated on a 50:50 basis, with each project allowed to employ up to one-half the workforce ceiling (POLCY1 = 1). Results of cost minimization simulation runs are shown in Figure 14; summary results are shown in the appendix. Starting one project 160 days after the other provides the optimal degree of overlap.

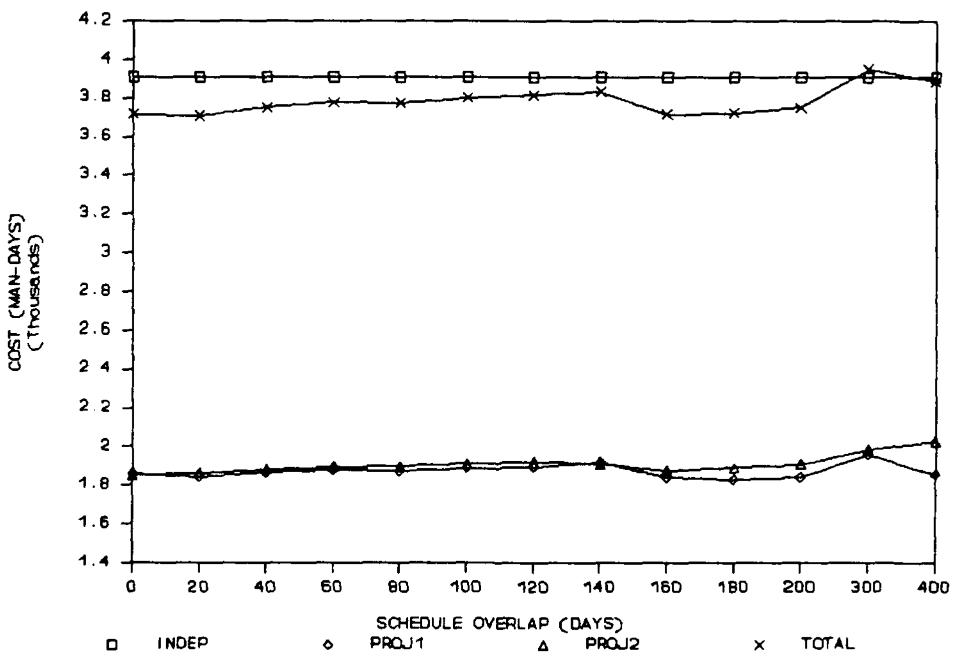


Figure 14. Overlap Results--Workforce Ceiling and Allocation

5. Hiring and Transferring Aggressiveness

In this set of simulations, the variables affecting the aggressiveness in hiring (TMPRMR) and receiving transfers (TAGRSV) were changed to model a situation in which the manager is more aggressive in these areas. TMPRMR was decreased from 50 to 25 and TAGRSV was decreased from one to .5. Note that a decrease in these variables caused an increase in aggressiveness. This is the last set of simulations in which the priority is dynamically set. Figure 15 shows the results of the simulation runs for optimizing overlap in regard to minimizing cost. The appendix provides a summary of these results. In this setting the optimal degree of overlap occurs when one project starts 300 days after the other.

6. Project Starting First Has Priority

In this set of simulations, as in the next, the project priority is set statically (PRTYSW = 1). That project which will have priority is determined at the beginning of the simulation by the manager and remains unchanged throughout. In this and the next set of simulations, project one has priority (TRPY11 = 1). In this set, project one is also the project which starts first; therefore, when the X-axis is labelled, for instance, 100, this means that project one started at time zero and project two started at time 100. Figure 16 shows the results of this experiment in which the optimal degree of overlap is

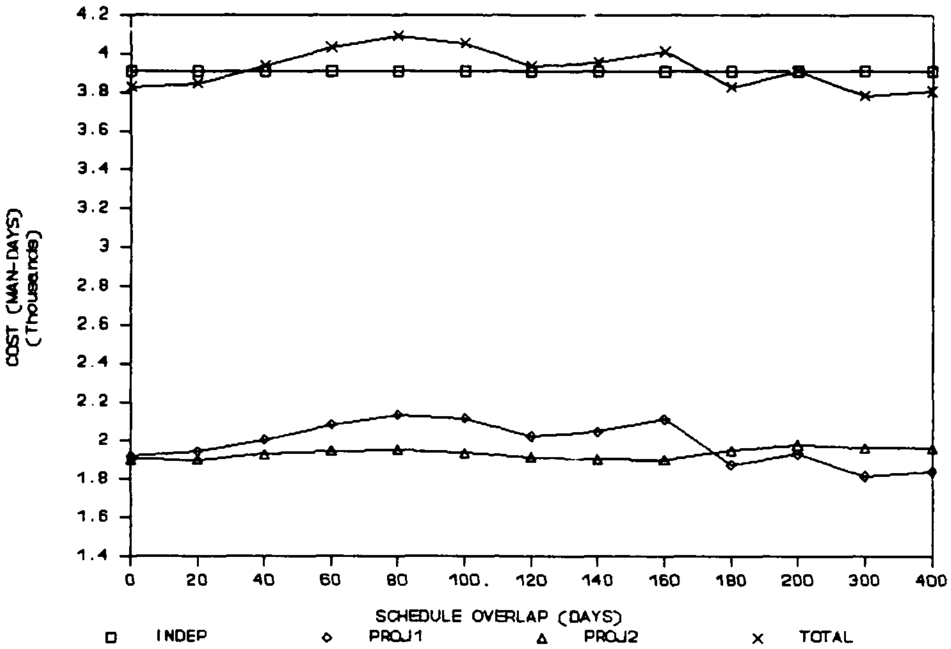


Figure 15. Overlap Results--Hiring and Transferring Aggressiveness

reached when project one starts 120 days before project two. A summary of these results is provided in the appendix. These results will be used in determining a starting point for the second set of experiments.

7. Project Starting Last Has Priority

In this set, project one also has priority but in contrast to the sixth set of simulations, above, it is the project which starts last; therefore, when the X-axis is labelled, for instance, 100, this means that project one started at time 100 and project two started at time zero.

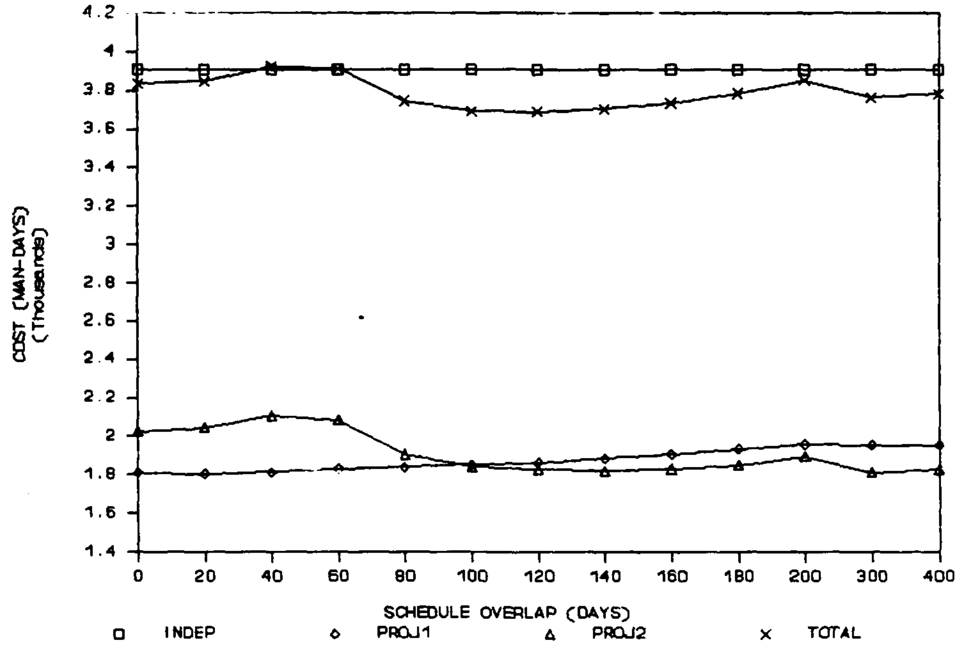


Figure 16. Overlap Results--Project Starting First Has Priority

Figure 17 shows the results of this experiment in which the optimal degree of overlap occurs when project one starts 100 days after project two. The appendix provides a summary of the results. These results will be used in determining a starting point for the third set of experiments.

8. <u>Summary</u>

Figure 18 provides a graph showing the different optimum degrees of overlap with which to minimize cost for each simulation in experiment set one. The results attained in this experiment set all provide points for further analysis. To provide the reader with an understanding of

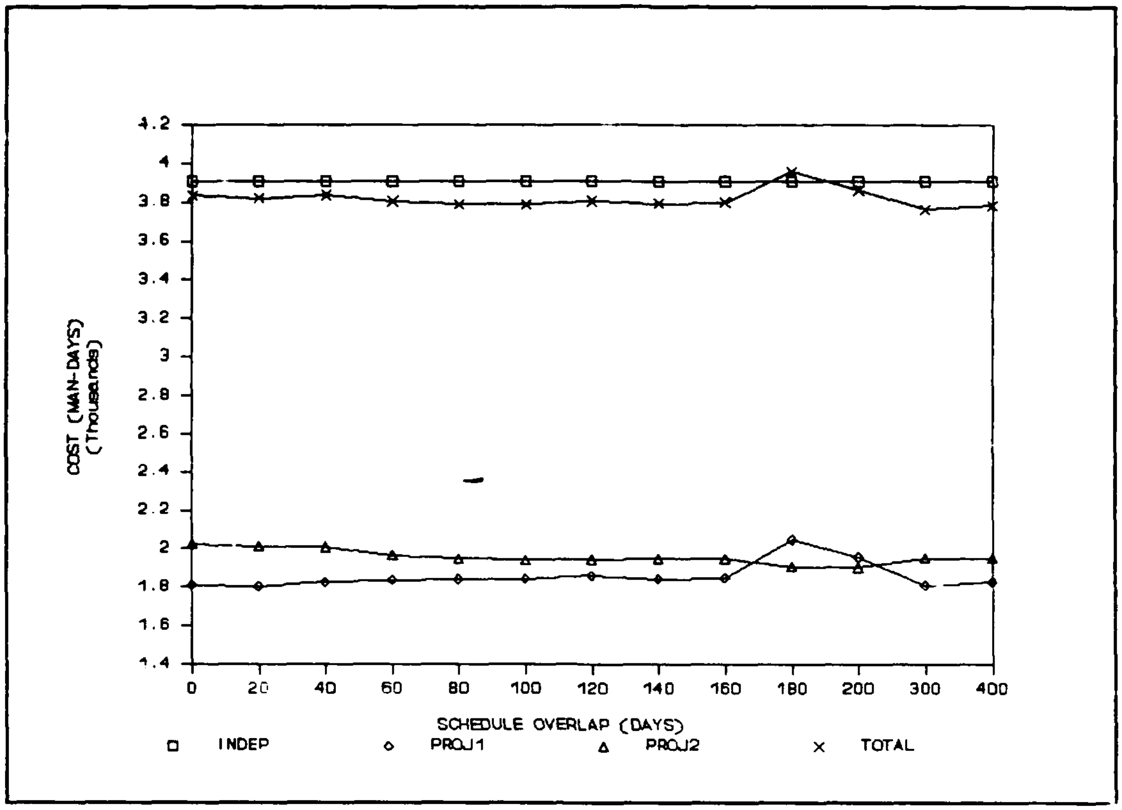


Figure 17. Overlap Results--Project Starting Last Has Priority

the factors that may lead to these results, a short analysis of two of the more extreme results will be presented here.

The first simulation to be discussed is simulation three in which the nominal ceiling on the total workforce was reduced from 30 to 20. In this simulation, costs were minimized when one project started 400 days after the other. The effects of hiring and transferring people may be the reason for this. For instance, when two projects run at approximately the same time as is the case when, say, project one starts 60 days after project two, transferring of personnel does not occur until relatively late in the

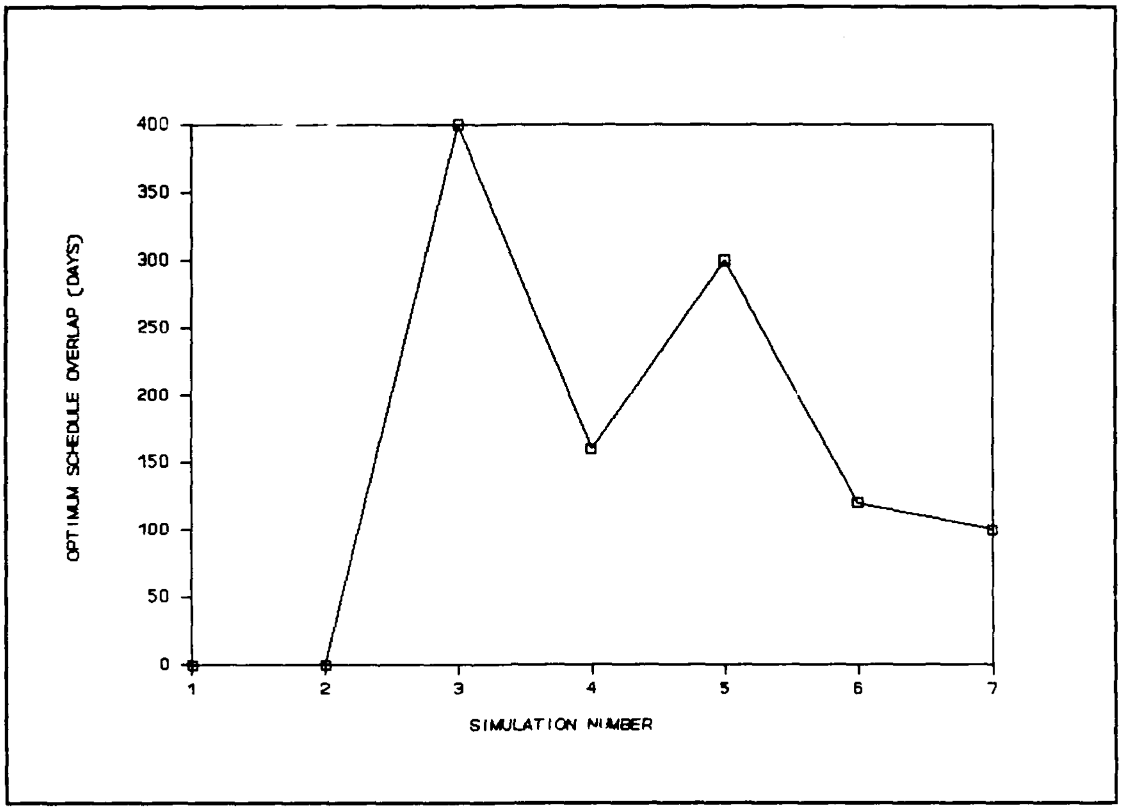


Figure 18. Graphic Results of Experiment Set One

projects as neither can afford to give them up earlier. This coupled with the decreased ability to hire as a result of the decrease in the workforce ceiling leads to less overall productivity. The change in productivity happens since transferred workers are assimilated later in the projects and are not able to "pull their load" for very long. Additionally, new workers are fewer in number than when the workforce ceiling is higher. When productivity is decreased, costs increase. In the case in which the projects start very far apart, as in this simulation in which one project starts 400 days after the other, the

project starting later is able to get transfers almost immediately since the other project has completed. The reduced number of people it can hire does not affect it in an adverse way because the transferred people contribute their share to the accomplishment of the workload throughout the project's lifecycle.

The other simulation of interest is the fifth simulation in which the aggressiveness of the manager in hiring and transferring is increased. The minimal cost is achieved when one project starts 300 days after the other. This is also caused by hiring and transferring. When the projects are running at approximately the same time, transfers occur throughout the life of both projects. When one project ends, the other aggressively seeks transfers even though it may be near completion. This decreases productivity and increases cost. When the projects start further apart, though, transfers occur earlier in the life of the second project allowing earlier realization of the benefits in productivity of the transferred workers and thus reducing cost.

This brief analysis of these two simulations provides insight into some of the factors affecting software project management in a multiproject environment. A more detailed analysis of these as well as the other simulations in this experiment set should increase the understanding of

the complex and interdependent variables affecting cost minimization under different situations.

D. EXPERIMENT SET TWO

The second set of experiments involved simulations run when the project starting first had priority. As illustrated in Figure 16, costs were minimized when the project having priority, project one, began 120 days before the project without priority. In each of the follow-on simulations run under this scenario, the start date of the second project was set to 120. Other parameters of note which remained unchanged throughout this scenario, unless otherwise indicated, include the project priority as already discussed, and the workforce ceiling allocation policy. The default value for this parameter was such that the workforce ceiling was allocated on a 50:50 basis between projects. Also, the nominal ceiling on the total workforce was set to 30 thus allowing no more than 30 employees in the entire organization. Unlike the previous set of experiments these were not conducted to determine the optimum overlap to minimize cost. Rather, as stated above, the overlap was set and other variables were manipulated in order to provide points of comparison between different conditions in an optimum overlap situation. These results are graphically presented in Figure 19. Table 1 provides a summary of the simulations run in this scenario. The names of each

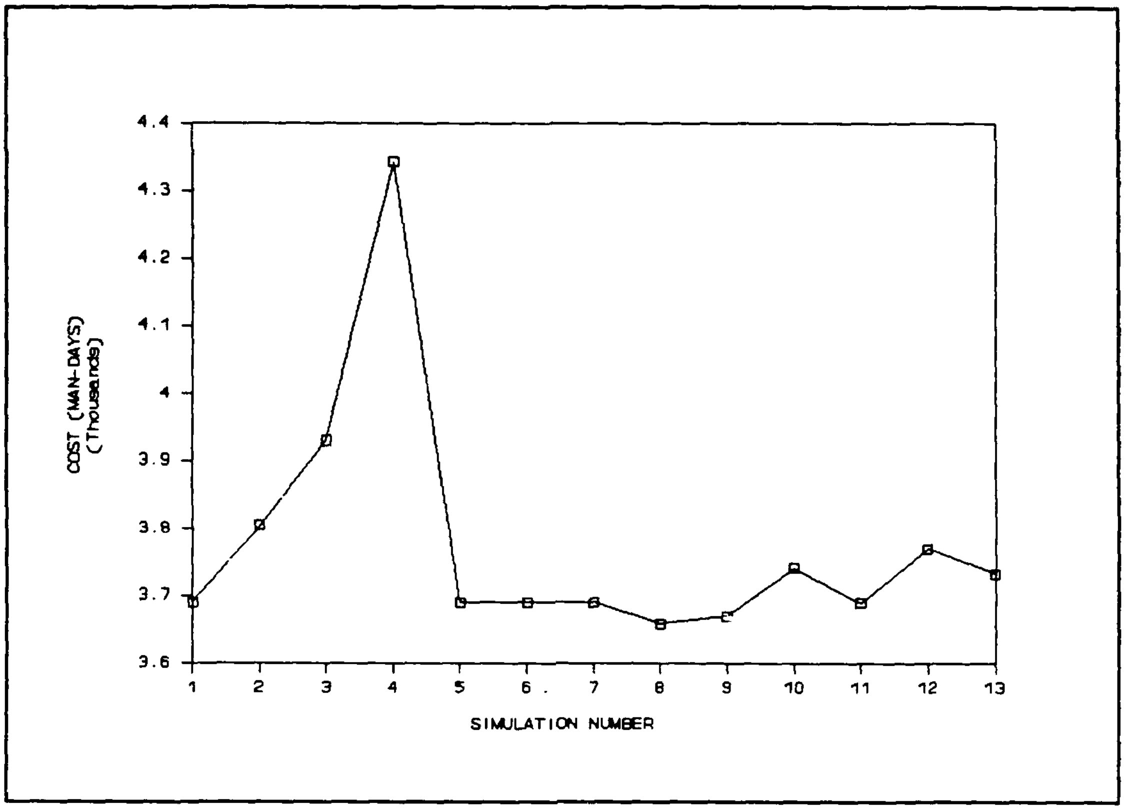


Figure 19. Graphic Results of Experiment Set Two

independent variable are explained in the section pertaining to that simulation. The reader will note that several of the variables manipulated in the first set of experiments were also changed in this and the third set of experiments.

1. Baseline

The first simulation presented is the "baseline" simulation in which project one has higher priority, project one started 120 days before project two, the workforce ceiling allocation policy is 50:50, and the ceiling on the total workforce is 30. This simulation provides a basis for comparisons with others within this experiment set.

TABLE 1

RESULTS FROM EXPERIMENT SET TWO SIMULATIONS

	Independent Variable	Cost (Man-days)	Schedule (Days)	Transfers 2 to 1	Transfers 1 to 2
1	BASELINE	3690.93	519.50	-8.84	8.84
2	TRPY11	3804.75	447.00	2.34	-2.34
3	PRTYSW	3929.72	468.00	-16.21	16.21
4	POLCY1	4343.44	514.50	-16.89	16.89
5	TAGRSV	3690.93	519.50	[illegible].84	8.84
6	T2T1F2 T1T2F2	3690.93	519.50	-8.84	8.84
7	TB2T11 TB1T21	3690.26	519.50	-8.84	8.84
8	TC2T11 TC1T21	3659.45	540.50	-8.24	8.24
9	FORGETa	3670.27	541.00	-8.33	8.33
10	FORGETb	3742.06	501.50	-9.34	9.34
11	TMP1R2 TMP1R1	3690.03	519.50	-8.84	8.84
12	TWRL2T1a TWRL1T2a	3770.12	618.50	-12.85	12.85
13	TWRL2T1b TWRL1T2b	3733.06	498.00	6.34	-6.34

Figure 20 provides a statistical report on the results of this simulation. The statistical reports for all simulations to be presented in this and the next section will be identical in format to that presented in this figure. These reports are, for the most part, self-explanatory. Note that statistics, including total effort,

PROJECT STATISTICS:			
			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	374.50	DAYS	
TOTAL EFFORT ONE	1,863.02	MAN-DAYS	
QA EFFORT ONE	457.20	MAN-DAYS	.25
DEVELOP EFFORT ONE	863.15	MAN-DAYS	.46
REWORK EFFORT ONE	261.58	MAN-DAYS	.14
TESTING EFFORT ONE	232.22	MAN-DAYS	.12
TRAINING EFFORT ONE	48.86	MAN-DAYS	.03
OVERALL-PRODUCTIVITY ONE	13.10	TASKS/MAN-DAY	
COMPLETION TIME TWO	519.50	DAYS	
TOTAL EFFORT TWO	1,827.91	MAN-DAYS	
QA EFFORT TWO	411.77	MAN-DAYS	.23
DEVELOP EFFORT TWO	881.43	MAN-DAYS	.48
REWORK EFFORT TWO	265.20	MAN-DAYS	.15
TESTING EFFORT TWO	245.93	MAN-DAYS	.13
TRAINING EFFORT TWO	23.58	MAN-DAYS	.01
OVERALL-PRODUCTIVITY TWO	13.35	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 8.84	MEN	
NET TRANSFERS 1 TO 2	8.84	MEN	
TOTAL EFFORT - BOTH	3,690.93	MAN-DAYS	

Figure 20. Simulation 1--Statistical Results

are presented for project one first followed by those for project two. Finally, the net transfers between projects (transfers from a project subtracted from transfers into that project) are shown followed by the total effort in man-days of the combined projects. It is the total effort, whether for each project or combined, which represents the "cost" inherent to each situation.

Graphical reports identical in format to Figures 21 and 22 will also be presented for each simulation throughout this and the following section. Figure 21 illustrates the relationship between the scheduled completion dates (SCHCDT), measured in days, of the two projects as well as the relationship between the total workforce (TOTWF), measured in men, of both projects. Also of interest is the relative relationship between the values of these variables themselves. For instance, project two has neither a scheduled completion date or any workforce assigned it until it begins at time 100. Once it begins, however, the scheduled completion date remains relatively stable then drops and finally rises again. The total workforce consistently rises throughout the life of the project and then drops rapidly once it is completed. Comparisons of absolute values of these variables is inadvisable because they are plotted on different scales, as can be seen on the left hand side of the graphs. Identification of which scale belongs to which variable can be made by comparing the minimum and maximum value of the scale to the figures immediately following the variables at the top of the graph.

Figure 22 presents the relationship between the total workforce (TOTWF) and the transferred workforce (TRNFWF), both of which are measured in number of men. Recall that as transferred individuals are assimilated into

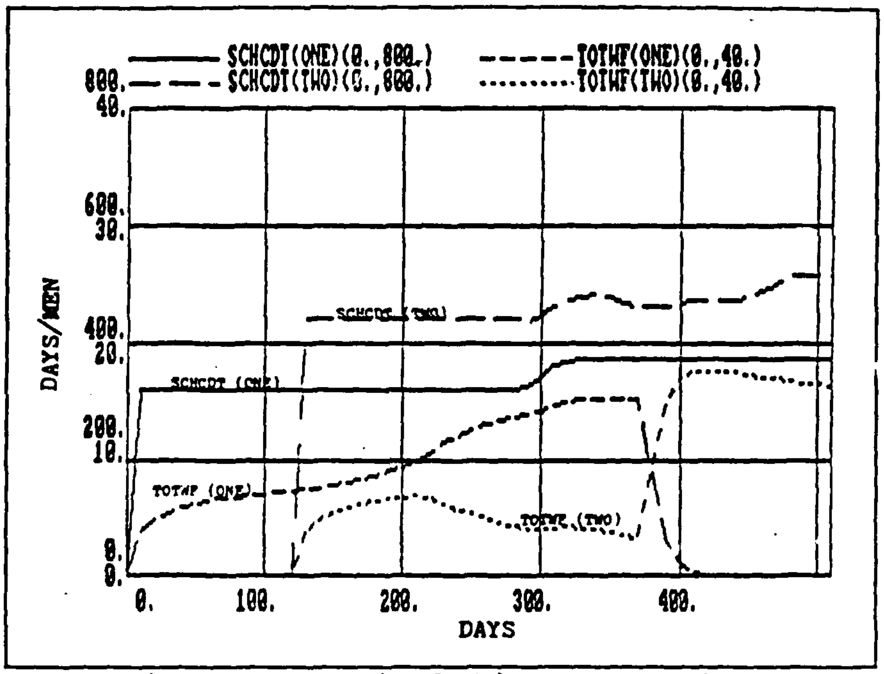


Figure 21. Simulation 1--Graph 1

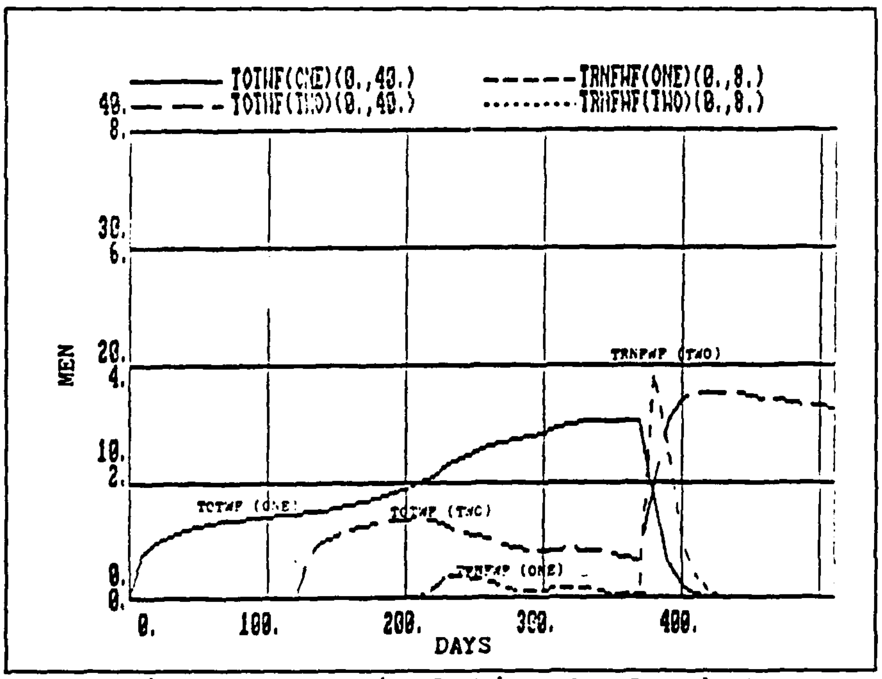


Figure 22. Simulation 1--Graph 2

the workforce of the gaining project, they become experienced workforce and are no longer reflected in the TRNFWF value. Caution is once again advised in any attempt to compare absolute values for these variables for the same reason mentioned in the paragraph above. More interesting, in any case, is their movement on the graph relative to each other. Since in this simulation, as in most simulations, project one has priority, there will be no transfers to project two until project one completes. Note that in both graphs, as in all graphs presented as simulation results, time is measured in days.

2. <u>TRPY11</u>

In this simulation, the priority of the projects (TRPY11) was switched (from TRPY11 = 1 to TRYP11 = 0). In the default, project one has priority. In this simulation, project two was given priority and as such all transfers would occur in the direction of project one to project two until project two completes. Results from this run are shown in Figures 23, 24, and 25.

3. <u>PRTYSW</u>

The third simulation in this set involved changing the way in which priority is determined. Instead of a single project always having priority (PRTYSW = 1), as determined exogenously by management, the priority in this simulation is determined dynamically (PRTYSW = 0). This is comparable to the conditions under which the first five

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	447.00	DAYS	
TOTAL EFFORT ONE	1,945.46	MAN-DAYS	
QA EFFORT ONE	502.02	MAN-DAYS	.26
DEVELOP EFFORT ONE	874.32	MAN-DAYS	.45
REWORK EFFORT ONE	258.95	MAN-DAYS	.13
TESTING EFFORT ONE	257.17	MAN-DAYS	.13
TRAINING EFFORT ONE	52.99	MAN-DAYS	.03
OVERALL-PRODUCTIVITY ONE	12.54	TASKS/MAN-DAY	
COMPLETION TIME TWO	429.50	DAYS	
TOTAL EFFORT TWO	1,859.30	MAN-DAYS	
QA EFFORT TWO	423.02	MAN-DAYS	.23
DEVELOP EFFORT TWO	892.14	MAN-DAYS	.48
REWORK EFFORT TWO	268.14	MAN-DAYS	.14
TESTING EFFORT TWO	250.87	MAN-DAYS	.13
TRAINING EFFORT TWO	25.13	MAN-DAYS	.01
OVERALL-PRODUCTIVITY TWO	13.12	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	2.34	MEN	
NET TRANSFERS 1 TO 2	- 2.34	MEN	
TOTAL EFFORT - BOTH	3,804.75	MAN-DAYS	

Figure 23. Simulation 2--Statistical Results

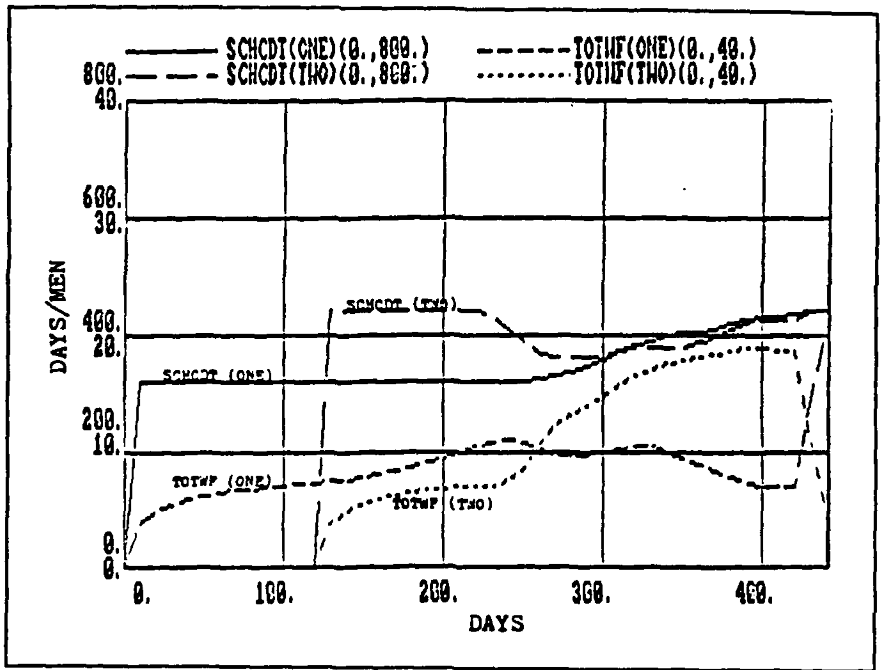


Figure 24. Simulation 2--Graph 1

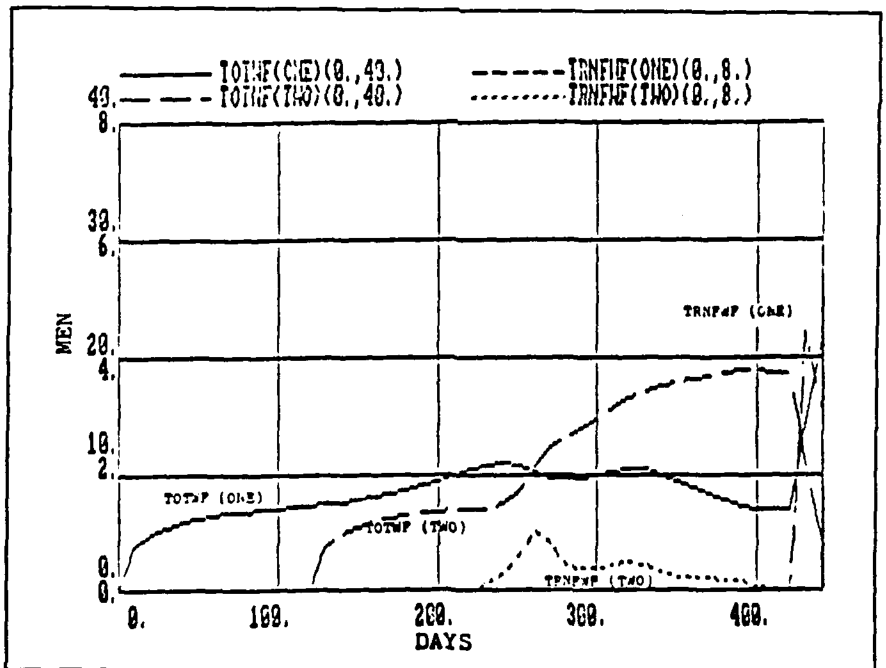


Figure 25. Simulation 2--Graph 2

simulations in experiment set one were run. Results from this simulation are shown in Figures 26, 27, and 28.

4. POLCY1

In this simulation, the variable changed was that which affects the management policy regarding how the workforce ceiling is allocated (POLCY1). In lieu of having a 50:50 allocation (POLCY1 = 1), in which each project gets 50 percent of the ceiling, the policy was changed (POLCY1 = 0). This simulation represents the effects of an allocation policy in which the project which has priority is allowed to hire in whatever numbers it needs up to the ceiling; the second project can hire only the workforce representing the difference between what the first project has hired and the organizational ceiling. Of note is the fact that in either case the default ceiling of 30 is sufficient for both projects to complete on time without undue pressure resulting from this ceiling if the workforce is acquired early enough to allow for assimilation. Results from this simulation are presented in Figures 29, 30, and 31.

5. TAGRSV

In the fifth simulation, the variable affecting the aggressiveness of the manager and his willingness to change the workforce assuming transfers will occur (TAGRSV) is changed. It is decreased from one to .5. The consequence of this change is to simulate a manager who is more willing to transfer people from the other project (project two).

PROJECT STATISTICS:			
			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	408.00	DAYS	
TOTAL EFFORT ONE	1,912.12	MAN-DAYS	
QA EFFORT ONE	488.53	MAN-DAYS	.26
DEVELOP EFFORT ONE	876.69	MAN-DAYS	.46
REWORK EFFORT ONE	262.54	MAN-DAYS	.14
TESTING EFFORT ONE	237.85	MAN-DAYS	.12
TRAINING EFFORT ONE	46.50	MAN-DAYS	.02
OVERALL-PRODUCTIVITY ONE	12.76	TASKS/MAN-DAY	
COMPLETION TIME TWO	468.00	DAYS	
TOTAL EFFORT TWO	2,017.60	MAN-DAYS	
QA EFFORT TWO	491.99	MAN-DAYS	.24
DEVELOP EFFORT TWO	920.28	MAN-DAYS	.46
REWORK EFFORT TWO	270.08	MAN-DAYS	.13
TESTING EFFORT TWO	312.28	MAN-DAYS	.15
TRAINING EFFORT TWO	22.97	MAN-DAYS	.01
OVERALL-PRODUCTIVITY TWO	12.09	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 16.21	MEN	
NET TRANSFERS 1 TO 2	16.21	MEN	
TOTAL EFFORT - BOTH	3,929.72	MAN-DAYS	

Figure 26. Simulation 3--Statistical Results

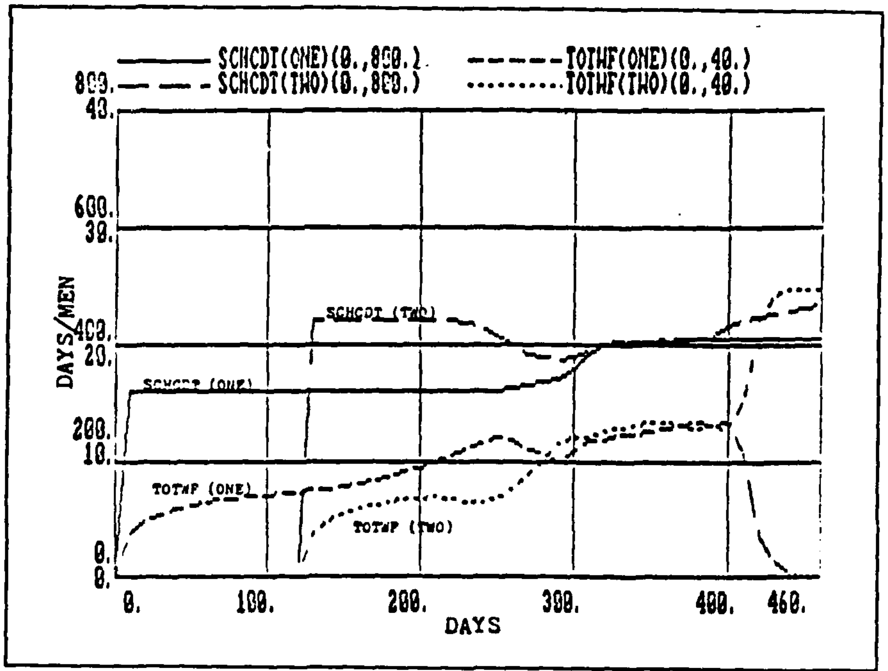


Figure 27. Simulation 3--Graph 1

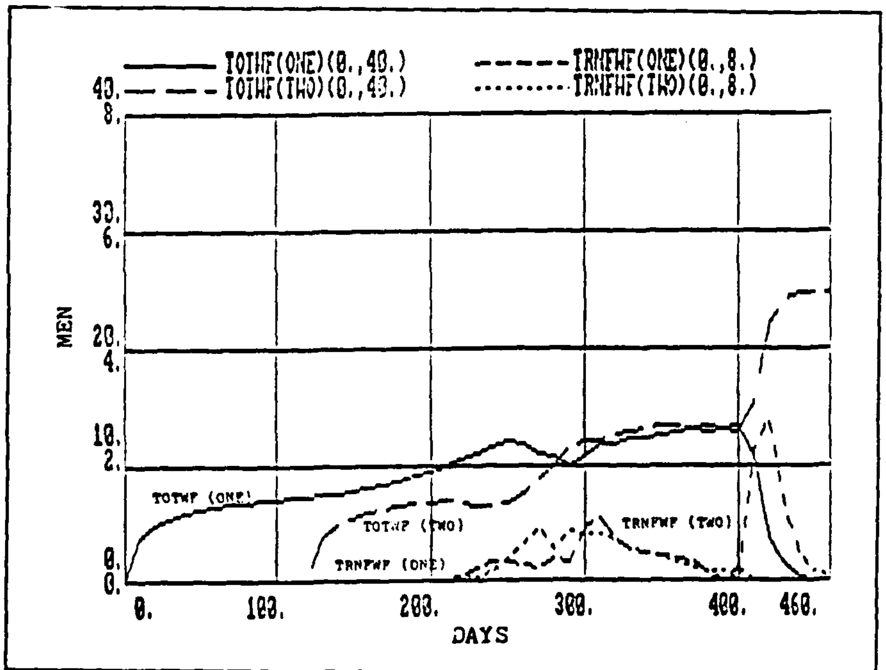


Figure 28. Simulation 3--Graph 2

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	372.00	DAYS	
TOTAL EFFORT ONE	1,953.53	MAN-DAYS	
QA EFFORT ONE	473.00	MAN-DAYS	.24
DEVELOP EFFORT ONE	878.74	MAN-DAYS	.45
REWORK EFFORT ONE	265.42	MAN-DAYS	.14
TESTING EFFORT ONE	260.95	MAN-DAYS	.13
TRAINING EFFORT ONE	75.41	MAN-DAYS	.04
OVERALL-PRODUCTIVITY ONE	12.49	TASKS/MAN-DAY	
COMPLETION TIME TWO	514.50	DAYS	
TOTAL EFFORT TWO	2,389.91	MAN-DAYS	
QA EFFORT TWO	517.59	MAN-DAYS	.22
DEVELOP EFFORT TWO	1079.8	MAN-DAYS	.45
REWORK EFFORT TWO	318.56	MAN-DAYS	.13
TESTING EFFORT TWO	422.57	MAN-DAYS	.18
TRAINING EFFORT TWO	51.36	MAN-DAYS	.02
OVERALL-PRODUCTIVITY TWO	10.21	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 16.89	MEN	
NET TRANSFERS 1 TO 2	16.89	MEN	
TOTAL EFFORT - BOTH	4,343.44	MAN-DAYS	

Figure 29. Simulation 4--Statistical Results

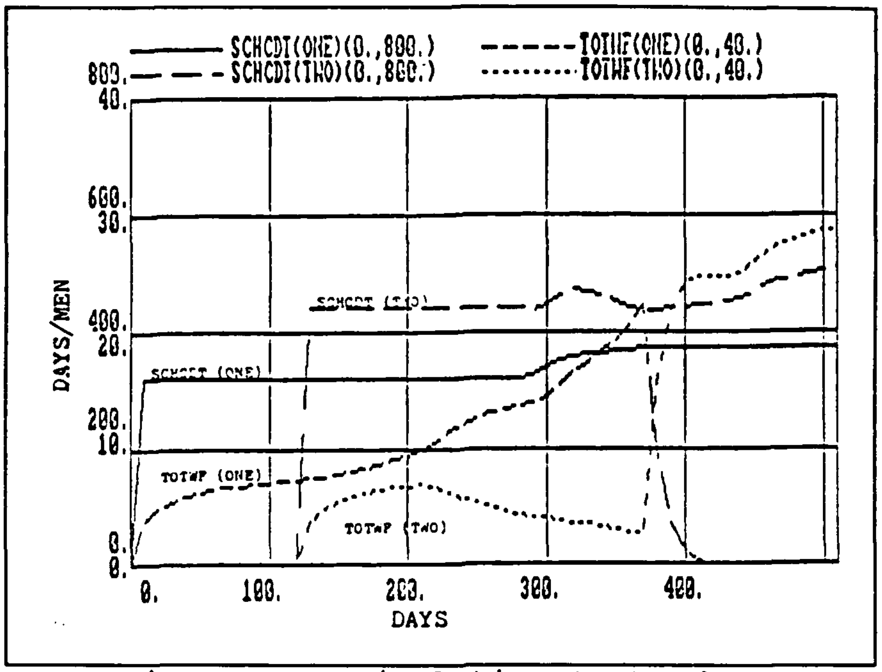


Figure 30. Simulation 4--Graph 1

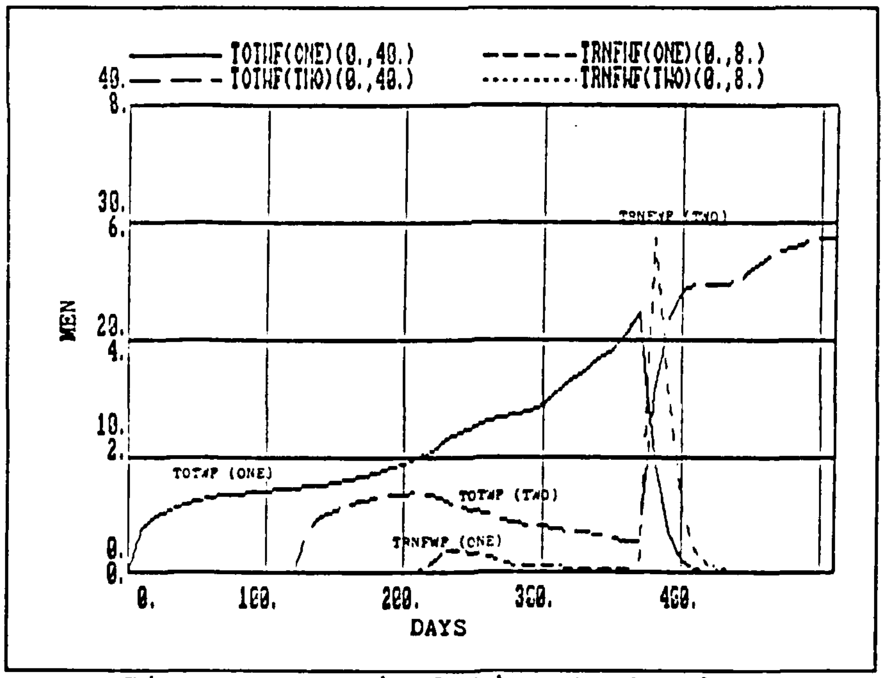


Figure 31. Simulation 4--Graph 2

Results from this simulation are shown in Figures 32, 33, and 34.

6. T2T1F2 and T1T2F2

Similar to the fifth simulation, the effect of the change in this run of the model was to simulate a manager who is more willing to transfer workforce by force from the other project to meet his manpower needs. These variables (T2T1F2 and T1T2F2) model willingness to force transfers as a function of the percent reported completed of the second project. They are originally set to values which indicate an unwillingness on the manager's part to force transfers from a project just beginning. This is because the manager realizes the importance of not disrupting a project in its early stages, when it is building its core team. Thus even though project one has priority, its manager would not be willing to force transfers from project two because he knew it was in its "building up" stage. In this case both the variable affecting project one and its equivalent (T2T1F2 and T2T1F2) were increased in value such that this period of non-disruption is denied. The default values of these variables are 0/.2/.5/.9/1/1 while the new values as used in this simulation are 1/1/1/1/1/1. Values such as these represent table functions in the Dynamo language. In table functions each number is associated with the occurrence of an event. For instance, in this example, a manager would have "0" willingness to force transfers when project two was

PROJECT STATISTICS			
			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	374.50	DAYS	
TOTAL EFFORT ONE	1,863.02	MAN-DAYS	
QA EFFORT ONE	457.20	MAN-DAYS	.25
DEVELOP EFFORT ONE	863.15	MAN-DAYS	.46
REWORK EFFORT ONE	261.58	MAN-DAYS	.14
TESTING EFFORT ONE	232.22	MAN-DAYS	.12
TRAINING EFFORT ONE	48.86	MAN-DAYS	.03
OVERALL-PRODUCTIVITY ONE	13.10	TASKS/MAN-DAY	
COMPLETION TIME TWO	519.50	DAYS	
TOTAL EFFORT TWO	1,827.91	MAN-DAYS	
QA EFFORT TWO	411.77	MAN-DAYS	.23
DEVELOP EFFORT TWO	881.43	MAN-DAYS	.48
REWORK EFFORT TWO	265.20	MAN-DAYS	.15
TESTING EFFORT TWO	245.93	MAN-DAYS	.13
TRAINING EFFORT TWO	23.58	MAN-DAYS	.01
OVERALL-PRODUCTIVITY TWO	13.35	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 8.84	MEN	
NET TRANSFERS 1 TO 2	8.84	MEN	
TOTAL EFFORT - BOTH	3,690.93	MAN-DAYS	

Figure 32. Simulation 5--Statistical Results

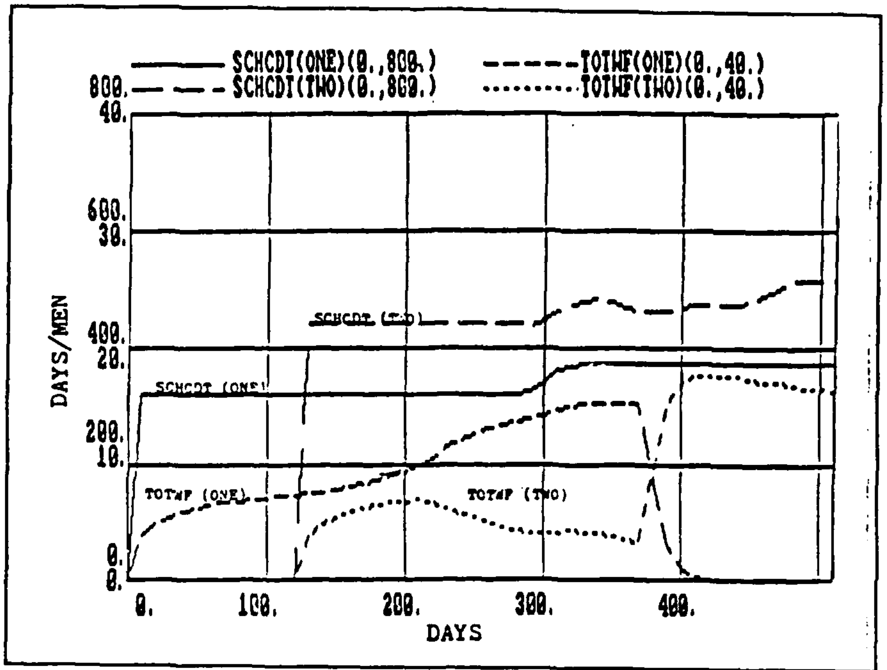


Figure 33. Simulation 5--Graph 1

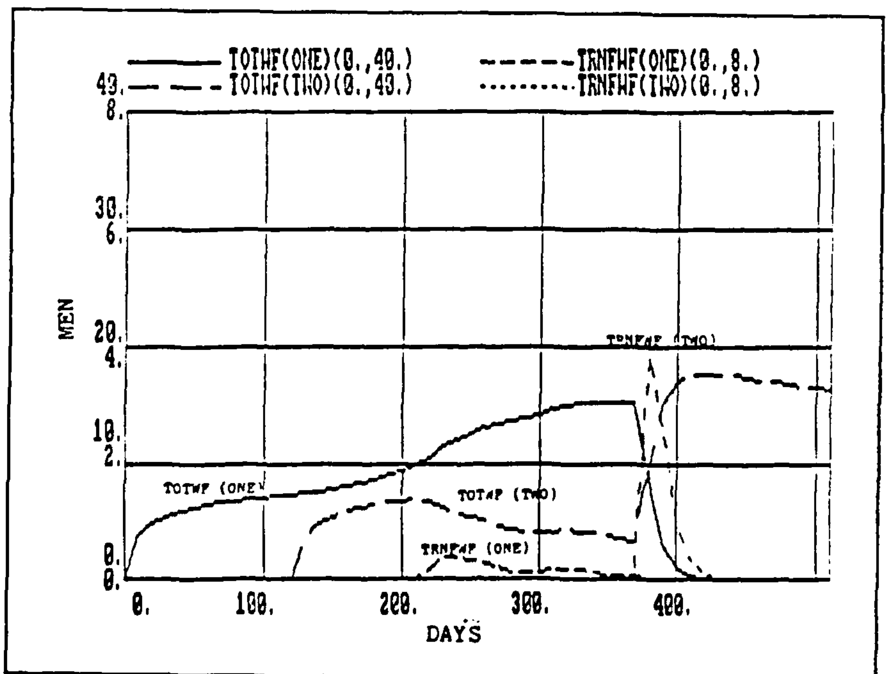


Figure 34. Simulation 5--Graph 2

reporting zero percent completion. A more detailed discussion of the table function and its application, while beyond the scope of this work, can be found in Alexander Pugh's book, Dynamo User's Manual. However, in several cases these types of values are included in the description of the simulation to enable duplication of these simulations in follow-up research. Results from this simulation are given in Figures 35, 36, and 37.

7. TB2T11 and TB1T21

In this simulation another variable and its equivalent (TB2T11 and TB1T21) were changed. These variables are used in conjunction with those described in simulation eight to ascertain the overall fraction of his workforce the manager can be forced to transfer. These variables provide input to this fraction as a function of the percent reported completed of the second project. In the default situation project one will not force transfers from project two at all until it is at least ten percent complete. The contribution of these two variables is zero until this time causing a zero fraction of the workforce to be forcibly transferred. The change effected in this simulation was such that these variables no longer had any effect on the overall fraction of the workforce to be transferred--a simulation which could be used to ascertain if the concept which these variables model is an actual concern of managers. If the change does not produce significantly

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	374.50	DAYS	
TOTAL EFFORT ONE	1,863.02	MAN-DAYS	
QA EFFORT ONE	457.20	MAN-DAYS	.25
DEVELOP EFFORT ONE	863.15	MAN-DAYS	.46
REWORK EFFORT ONE	261.58	MAN-DAYS	.14
TESTING EFFORT ONE	232.22	MAN-DAYS	.12
TRAINING EFFORT ONE	48.86	MAN-DAYS	.03
OVERALL-PRODUCTIVITY ONE	13.10	TASKS/MAN-DAY	
COMPLETION TIME TWO	519.50	DAYS	
TOTAL EFFORT TWO	1,827.91	MAN-DAYS	
QA EFFORT TWO	411.77	MAN-DAYS	.23
DEVELOP EFFORT TWO	881.43	MAN-DAYS	.48
REWORK EFFORT TWO	265.20	MAN-DAYS	.15
TESTING EFFORT TWO	245.93	MAN-DAYS	.13
TRAINING EFFORT TWO	23.58	MAN-DAYS	.01
OVERALL-PRODUCTIVITY TWO	13.35	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 8.84	MEN	
NET TRANSFERS 1 TO 2	8.84	MEN	
TOTAL EFFORT - BOTH	3,690.93	MAN-DAYS	

Figure 35. Simulation 6--Statistical Results

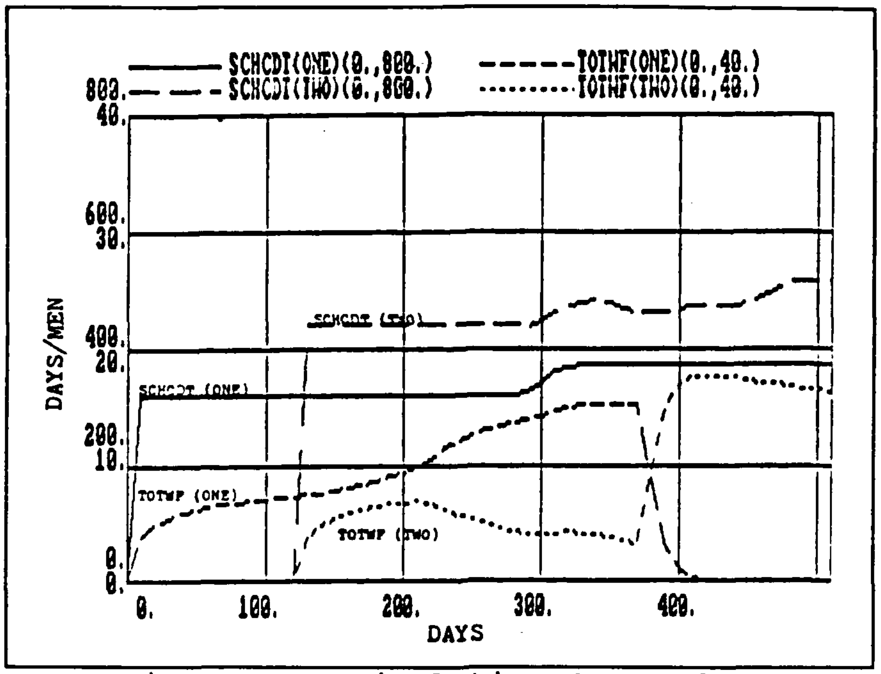


Figure 36. Simulation 6--Graph 1

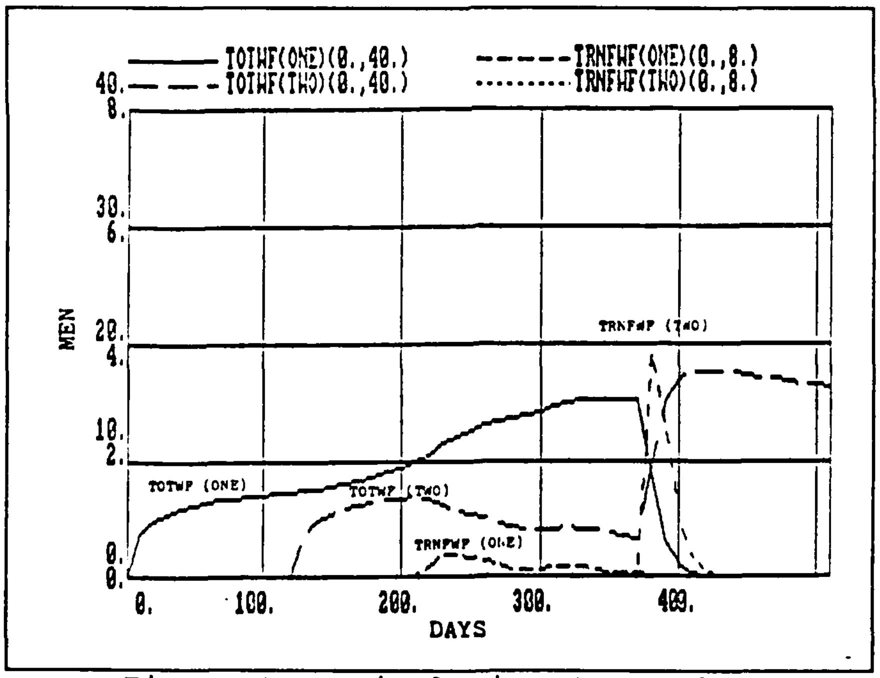


Figure 37. Simulation 6--Graph 2

different results from the baseline case, then this variable has little effect on the manager's decision. The default values of these variables are 0/.2/.5/.9/1/1 and the values on which this simulation were based are 1/1/1/1/1/1. Figures 38, 39, and 40 illustrate the results.

8. TC2T11 and TC1T21

In this simulation the variable affecting the fraction of his workforce a manager can be forced to transfer as a function of the cumulative recentness of transfers and its equivalent in the other project are increased (TC2T11 and TC1T21). These variables are used in conjunction with those described in simulation seven to ascertain the overall fraction of his workforce the manager can be forced to transfer. The default values of these variables (11 values ranging from .5 to zero) are such that if a manager has recently transferred out a large portion of his workforce he will not be forced to transfer any more individuals at the present time. These values were increased (all 11 values are now equal to the value one). The change effected in this simulation was such that these variables no longer had any affect on the overall fraction of the workforce to be transferred--a simulation which could be used to ascertain if the concept which these variables model is an actual concern of managers. If the change does not produce significantly different results from the baseline

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	374.50	DAYS	
TOTAL EFFORT ONE	1,862.98	MAN-DAYS	
QA EFFORT ONE	457.17	MAN-DAYS	.25
DEVELOP EFFORT ONE	863.13	MAN-DAYS	.46
REWORK EFFORT ONE	261.57	MAN-DAYS	.14
TESTING EFFORT ONE	232.24	MAN-DAYS	.12
TRAINING EFFORT ONE	48.85	MAN-DAYS	.03
OVERALL-PRODUCTIVITY ONE	13.10	TASKS/MAN-DAY	
COMPLETION TIME TWO	519.50	DAYS	
TOTAL EFFORT TWO	1,827.28	MAN-DAYS	
QA EFFORT TWO	411.82	MAN-DAYS	.23
DEVELOP EFFORT TWO	881.56	MAN-DAYS	.48
REWORK EFFORT TWO	265.19	MAN-DAYS	.15
TESTING EFFORT TWO	245.11	MAN-DAYS	.13
TRAINING EFFORT TWO	23.58	MAN-DAYS	.01
OVERALL-PRODUCTIVITY TWO	13.35	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 8.84	MEN	
NET TRANSFERS 1 TO 2	8.84	MEN	
TOTAL EFFORT - BOTH	3,690.26	MAN-DAYS	

Figure 38. Simulation 7--Statistical Results

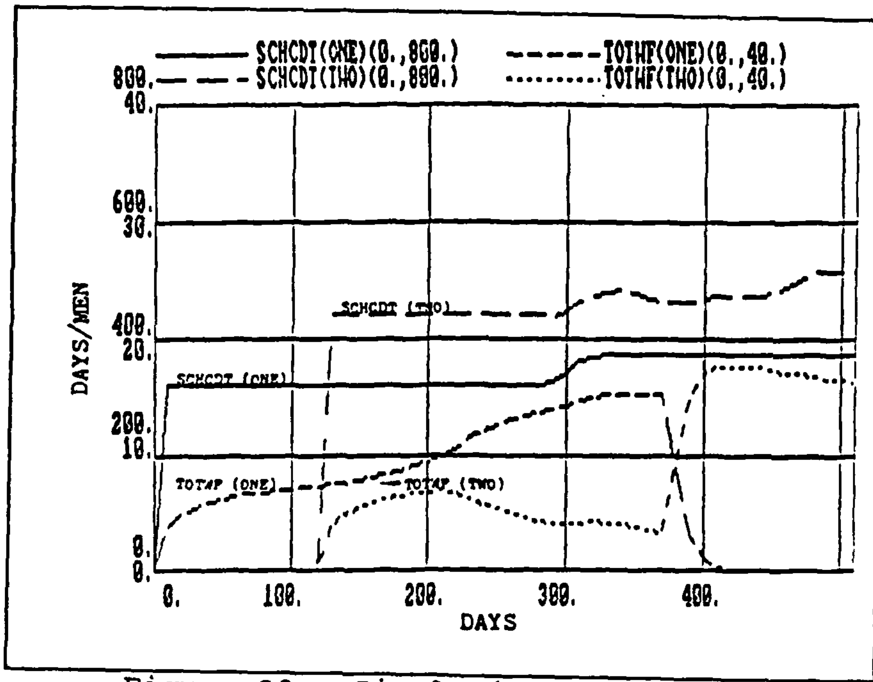


Figure 39. Simulation 7--Graph 1

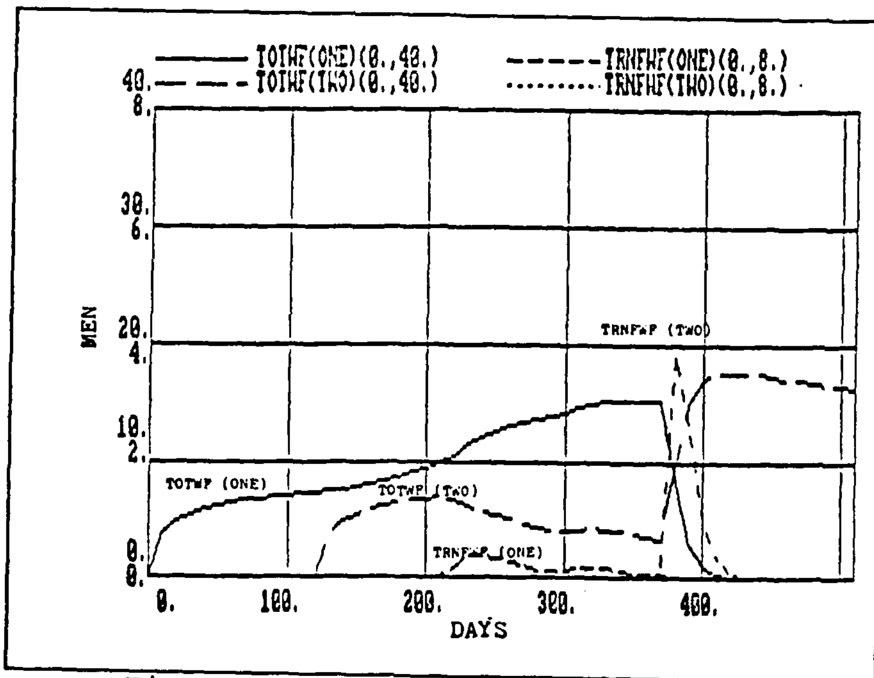


Figure 40. Simulation 7--Graph 2

case then this variable has little effect on the manager's decision. Figures 41, 42, and 43 pertain.

9. FORGETa

In the ninth simulation, the time it takes a manager to "forget" about recent transfers (FORGET) was decreased from the default value of 60 to 30. This variable affects the willingness of that manager to transfer more of his workforce. The lower the value of this variable, the more apt the manager is to allow transfers as he has already forgotten about relatively recent transfers. Results are provided in Figures 44, 45, and 46.

10. FORGETb

The amount of time it takes a manager to "forget" about recent transfers (FORGET) was increased over the default value from 60 to 120. More information is provided in the description of simulation nine. See the results in Figures 47, 48, and 49.

11. TMP1R2 and TMP1R1

In this experiment, the impact of the hiring ceiling on the willingness to force transfers from a project because its workforce could be replenished is changed as is its equivalent in the other project (TMP1R2 and TMP1R1). This change allows simulation of a situation in which the ceiling has less of an impact on the final decision than in the baseline case. Note that the result of the change is less of an impact although the default values of these variables

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	372.00	DAYS	
TOTAL EFFORT ONE	1,849.56	MAN-DAYS	
QA EFFORT ONE	451.31	MAN-DAYS	.24
DEVELOP EFFORT ONE	859.81	MAN-DAYS	.46
REWORK EFFORT ONE	261.22	MAN-DAYS	.14
TESTING EFFORT ONE	231.05	MAN-DAYS	.12
TRAINING EFFORT ONE	46.16	MAN-DAYS	.02
OVERALL-PRODUCTIVITY ONE	13.19	TASKS/MAN-DAY	
COMPLETION TIME TWO	540.50	DAYS	
TOTAL EFFORT TWO	1,809.90	MAN-DAYS	
QA EFFORT TWO	416.35	MAN-DAYS	.23
DEVELOP EFFORT TWO	870.64	MAN-DAYS	.48
REWORK EFFORT TWO	262.37	MAN-DAYS	.14
TESTING EFFORT TWO	236.57	MAN-DAYS	.13
TRAINING EFFORT TWO	23.96	MAN-DAYS	.01
OVERALL-PRODUCTIVITY TWO	13.48	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 8.24	MEN	
NET TRANSFERS 1 TO 2	8.24	MEN	
TOTAL EFFORT - BOTH	3,659.45	MAN-DAYS	

Figure 41. Simulation 8--Statistical Results

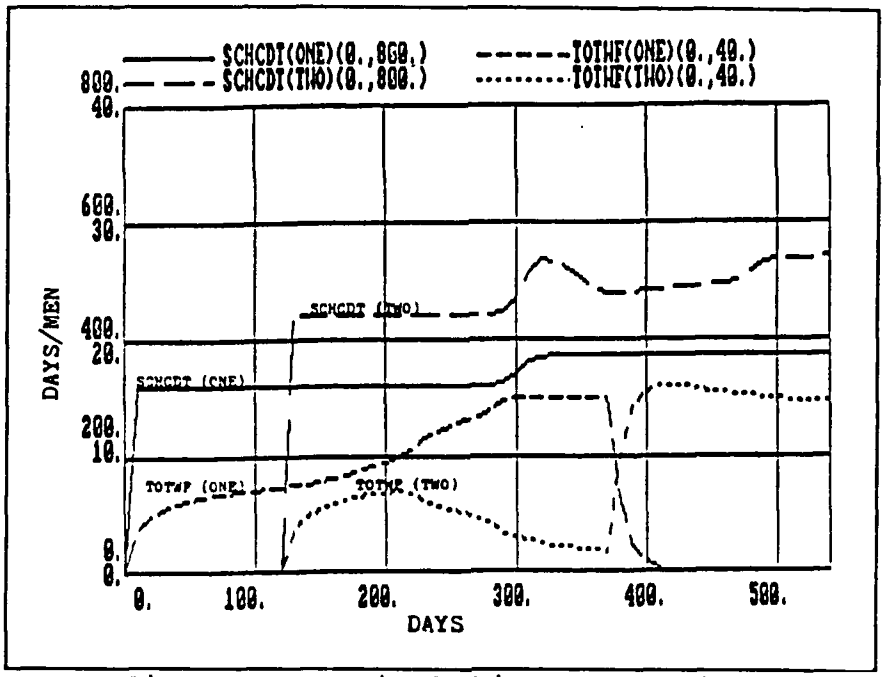


Figure 42. Simulation 8--Graph 1

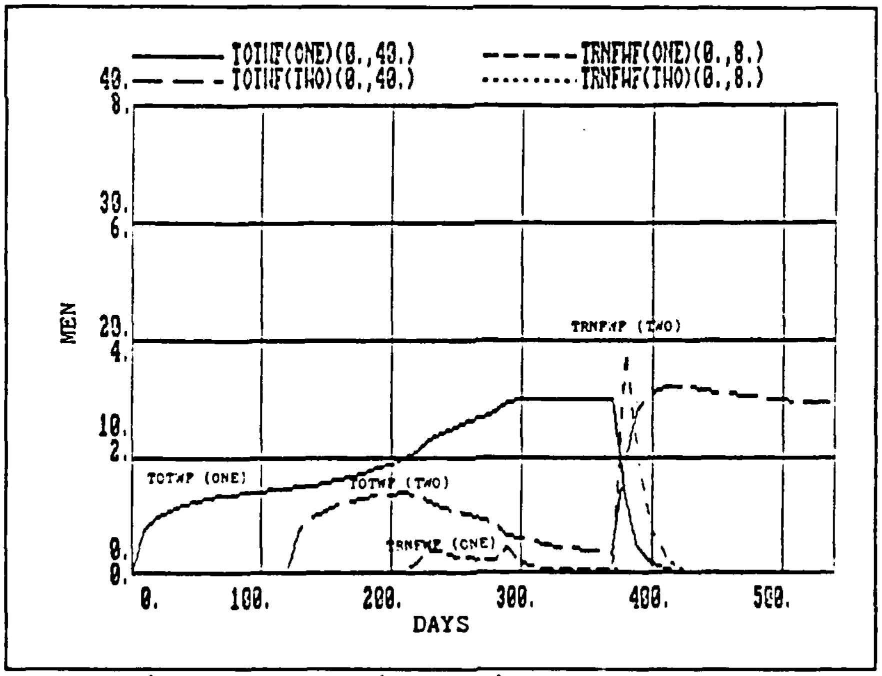


Figure 43. Simulation 8--Graph 2

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	374.50	DAYS	
TOTAL EFFORT ONE	1,863.02	MAN-DAYS	
QA EFFORT ONE	457.20	MAN-DAYS	.25
DEVELOP EFFORT ONE	863.15	MAN-DAYS	.46
REWORK EFFORT ONE	261.58	MAN-DAYS	.14
TESTING EFFORT ONE	232.22	MAN-DAYS	.12
TRAINING EFFORT ONE	48.86	MAN-DAYS	.03
OVERALL-PRODUCTIVITY ONE	13.10	TASKS/MAN-DAY	
COMPLETION TIME TWO	519.50	DAYS	
TOTAL EFFORT TWO	1,827.91	MAN-DAYS	
QA EFFORT TWO	411.77	MAN-DAYS	.23
DEVELOP EFFORT TWO	881.43	MAN-DAYS	.48
REWORK EFFORT TWO	265.20	MAN-DAYS	.15
TESTING EFFORT TWO	245.93	MAN-DAYS	.13
TRAINING EFFORT TWO	23.58	MAN-DAYS	.01
OVERALL-PRODUCTIVITY TWO	13.35	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 8.84	MEN	
NET TRANSFERS 1 TO 2	8.84	MEN	
TOTAL EFFORT - BOTH	3,690.93	MAN-DAYS	

Figure 44. Simulation 6--Statistical Results

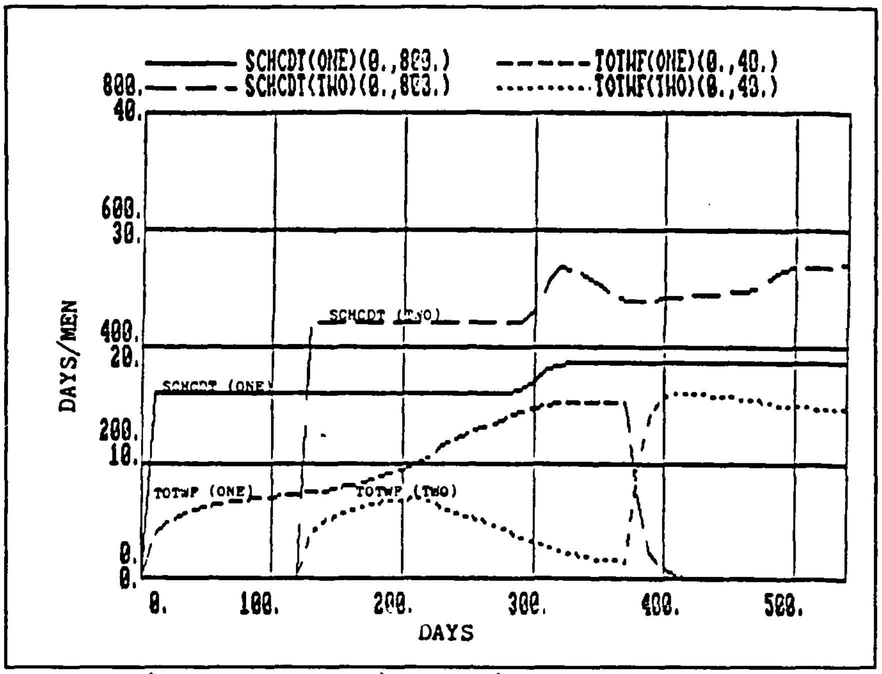


Figure 45. Simulation 9--Graph 1

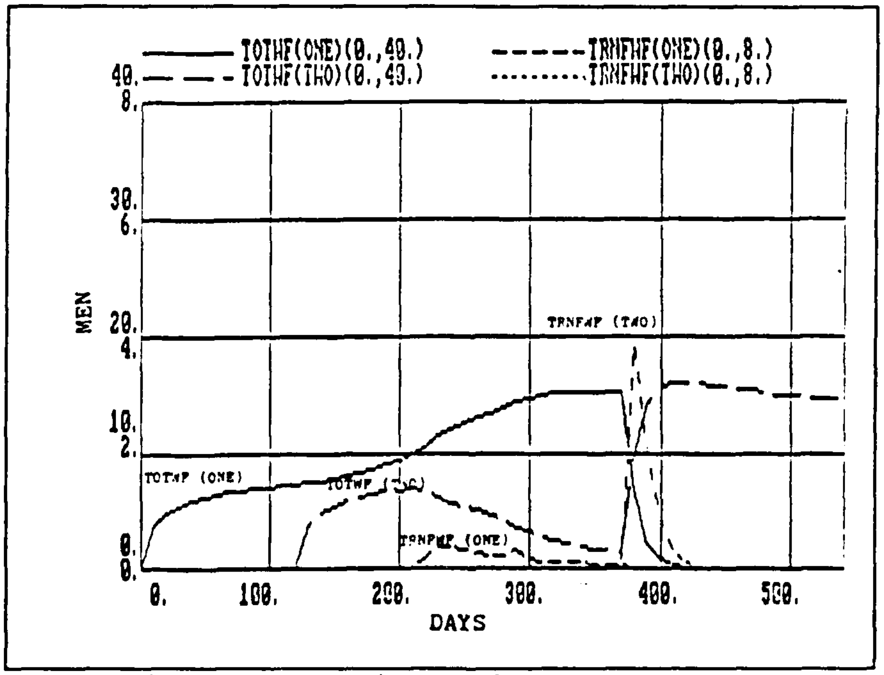


Figure 46. Simulation 9--Graph 2

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	377.50	DAYS	
TOTAL EFFORT ONE	1,875.87	MAN-DAYS	
QA EFFORT ONE	462.83	MAN-DAYS	.25
DEVELOP EFFORT ONE	866.13	MAN-DAYS	.46
REWORK EFFORT ONE	262.02	MAN-DAYS	.14
TESTING EFFORT ONE	233.66	MAN-DAYS	.12
TRAINING EFFORT ONE	51.22	MAN-DAYS	.03
OVERALL-PRODUCTIVITY ONE	13.01	TASKS/MAN-DAY	
COMPLETION TIME TWO	501.50	DAYS	
TOTAL EFFORT TWO	1,866.19	MAN-DAYS	
QA EFFORT TWO	413.94	MAN-DAYS	.22
DEVELOP EFFORT TWO	895.97	MAN-DAYS	.48
REWORK EFFORT TWO	269.71	MAN-DAYS	.14
TESTING EFFORT TWO	257.39	MAN-DAYS	.14
TRAINING EFFORT TWO	29.17	MAN-DAYS	.02
OVERALL-PRODUCTIVITY TWO	13.07	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 9.34	MEN	
NET TRANSFERS 1 TO 2	9.34	MEN	
TOTAL EFFORT - BOTH	3,742.06	MAN-DAYS	

Figure 47. Simulation 10--Statistical Results

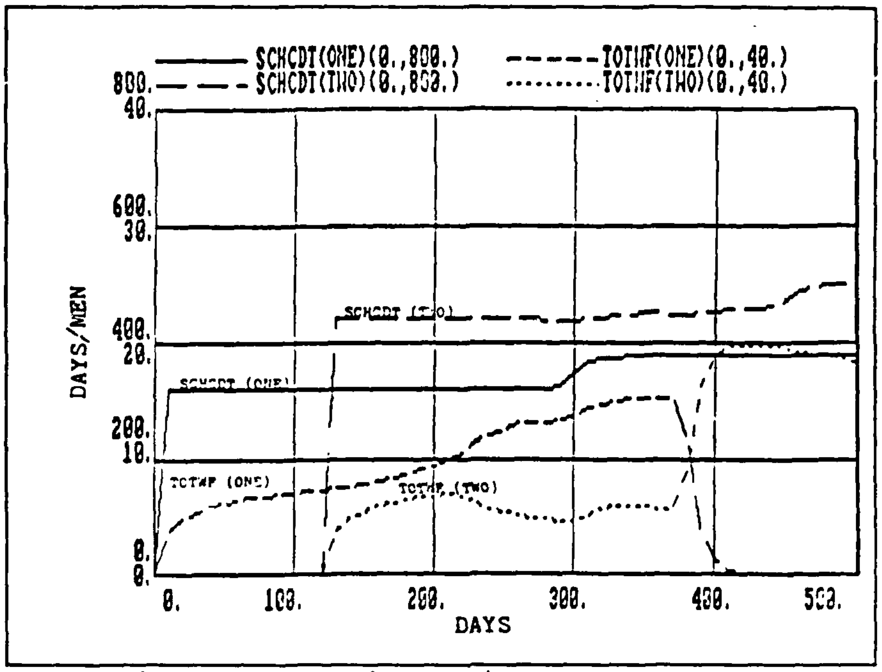


Figure 48. Simulation 10--Graph 1

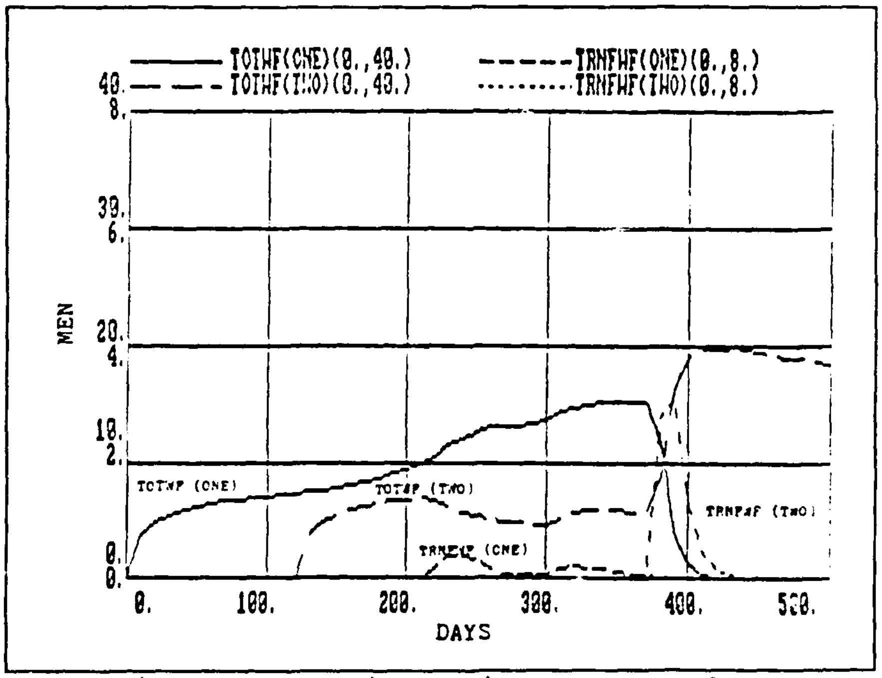


Figure 49. Simulation 10--Graph 2

were increased from 0/.5/.75/.9/.975/1/1/1/1/1/1 to all one's. The results of the simulation are presented in Figures 50, 51, and 52.

12. TWRL2T1a and TWRL1T2a

The manager's willingness to rely on the release of people from a completing project and its equivalent in the other project are the independent variables in this simulation (TWRL2T1 and TWRL1T2). This willingness is a ratio of the time remaining (for the completing project) to the hiring delay; the higher the ratio, the less apt the manager is to wait in the baseline scenario. In this simulation, this willingness was increased, from 1/.5/.25/.1/0/0, the default values, to 1/1/1/1/1/1. This increase simulates a manager who is always willing to rely on release of personnel from the other project regardless of how much longer it has before completion. Figures 53, 54, and 55 provide results.

13. TWRL2T1b and TWRL1T2b

Once again, the manager's willingness to rely on the release of people from a completing project is the independent variable. However, in this case, this willingness was decreased from the default values given in the description of simulation 12 to 0/0/0/0/0/0. This decrease causes the situation in which the manager will never rely on people from the other project based on its completion. Figures 56, 57, and 58 are relevant.

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	374.50	DAYS	
TOTAL EFFORT ONE	1,863.02	MAN-DAYS	
QA EFFORT ONE	457.20	MAN-DAYS	.25
DEVELOP EFFORT ONE	863.15	MAN-DAYS	.46
REWORK EFFORT ONE	261.58	MAN-DAYS	.14
TESTING EFFORT ONE	232.22	MAN-DAYS	.12
TRAINING EFFORT ONE	48.86	MAN-DAYS	.03
OVERALL-PRODUCTIVITY ONE	13.10	TASKS/MAN-DAY	
COMPLETION TIME TWO	519.50	DAYS	
TOTAL EFFORT TWO	1,827.91	MAN-DAYS	
QA EFFORT TWO	411.77	MAN-DAYS	.23
DEVELOP EFFORT TWO	881.43	MAN-DAYS	.48
REWORK EFFORT TWO	265.20	MAN-DAYS	.15
TESTING EFFORT TWO	245.93	MAN-DAYS	.13
TRAINING EFFORT TWO	23.58	MAN-DAYS	.01
OVERALL-PRODUCTIVITY TWO	13.35	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 8.84	MEN	
NET TRANSFERS 1 TO 2	8.84	MEN	
TOTAL EFFORT - BOTH	3,690.93	MAN-DAYS	

Figure 50. Simulation 11--Statistical Results

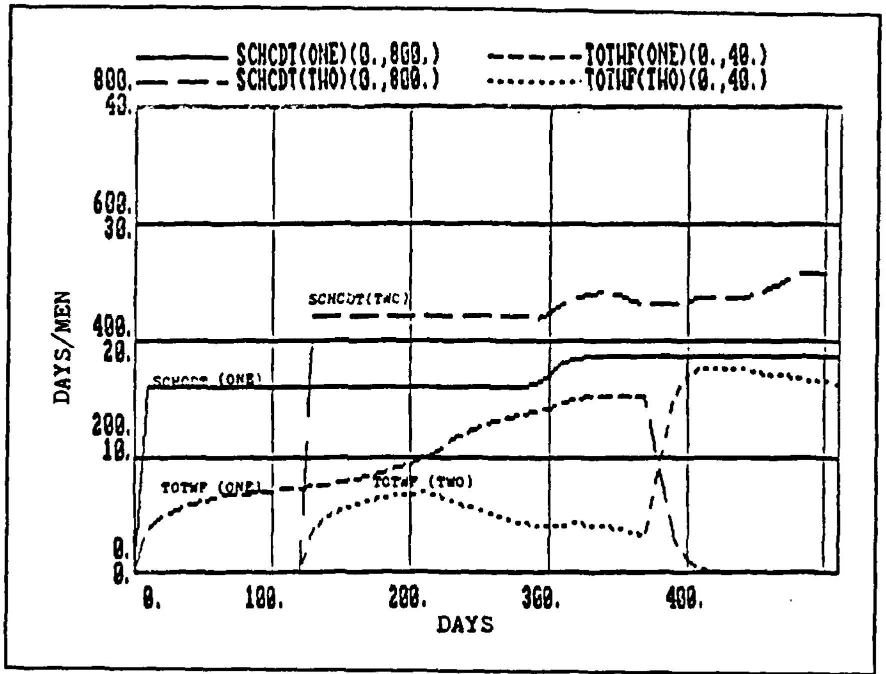


Figure 51. Simulation 11--Graph 1

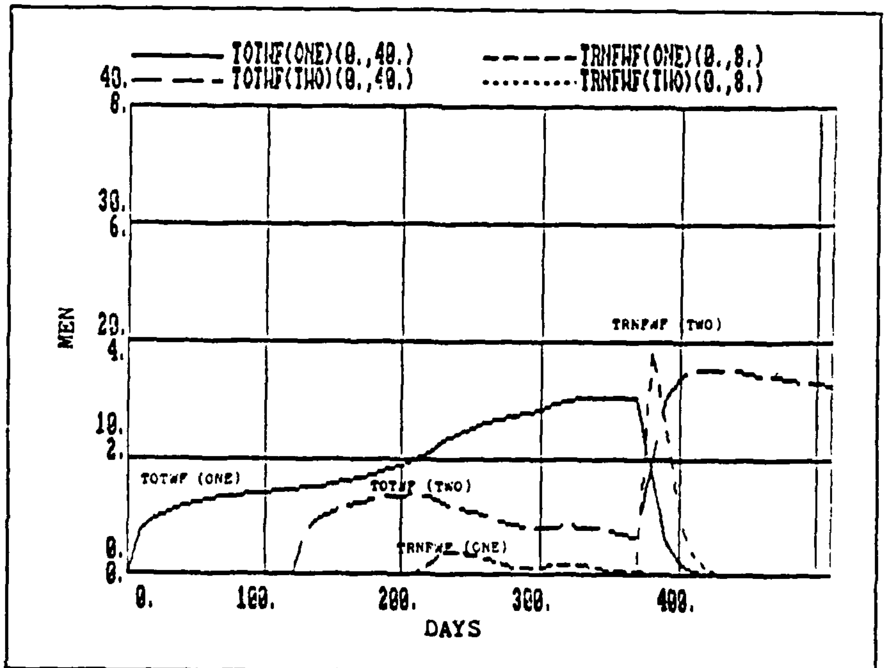


Figure 52. Simulation 11--Graph 2

PROJECT STATISTICS:			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	391.00	DAYS	
TOTAL EFFORT ONE	1,923.60	MAN-DAYS	
QA EFFORT ONE	482.27	MAN-DAYS	.25
DEVELOP EFFORT ONE	873.82	MAN-DAYS	.45
REWORK EFFORT ONE	264.67	MAN-DAYS	.14
TESTING EFFORT ONE	235.45	MAN-DAYS	.12
TRAINING EFFORT ONE	67.38	MAN-DAYS	.04
OVERALL-PRODUCTIVITY ONE	12.68	TASKS/MAN-DAY	
COMPLETION TIME TWO	618.50	DAYS	
TOTAL EFFORT TWO	1,846.52	MAN-DAYS	
QA EFFORT TWO	443.25	MAN-DAYS	.24
DEVELOP EFFORT TWO	875.76	MAN-DAYS	.47
REWORK EFFORT TWO	256.62	MAN-DAYS	.14
TESTING EFFORT TWO	259.72	MAN-DAYS	.14
TRAINING EFFORT TWO	11.17	MAN-DAYS	.01
OVERALL-PRODUCTIVITY TWO	13.21	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 12.85	MEN	
NET TRANSFERS 1 TO 2	12.85	MEN	
TOTAL EFFORT - BOTH	3,770.12	MAN-DAYS	

Figure 53. Simulation 12--Statistical Results

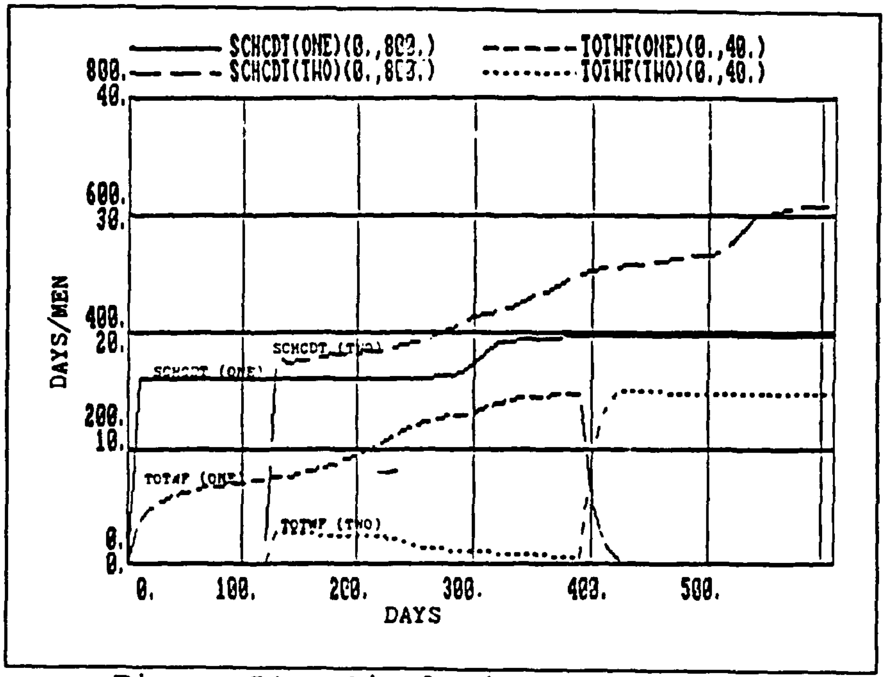


Figure 54. Simulation 12--Graph 1

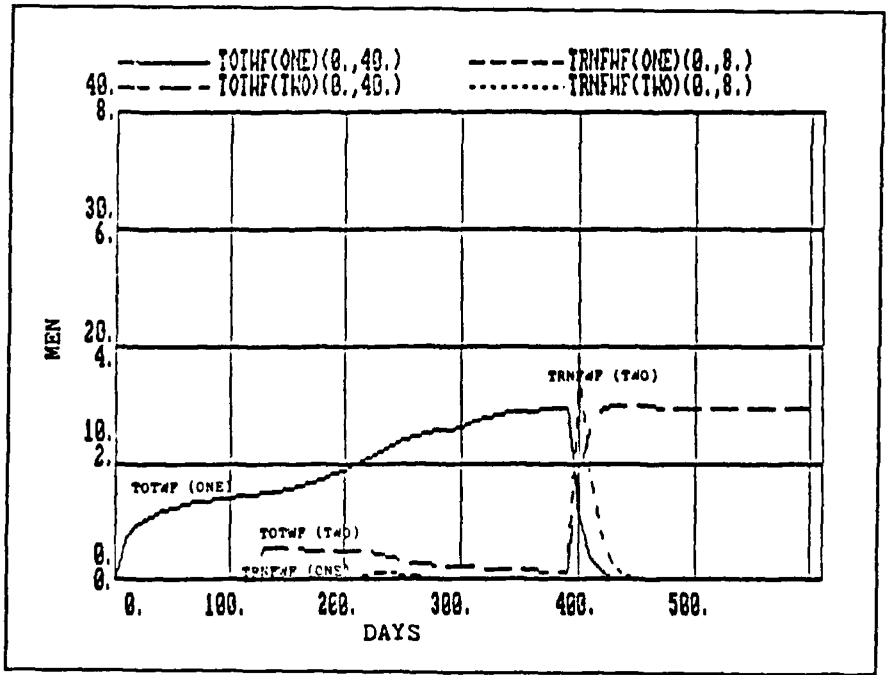


Figure 55. Simulation 12--Graph 2

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	364.50	DAYS	
TOTAL EFFORT ONE	1,889.58	MAN-DAYS	
QA EFFORT ONE	454.99	MAN-DAYS	.24
DEVELOP EFFORT ONE	869.06	MAN-DAYS	.46
REWORK EFFORT ONE	263.34	MAN-DAYS	.14
TESTING EFFORT ONE	256.79	MAN-DAYS	.14
TRAINING EFFORT ONE	45.40	MAN-DAYS	.02
OVERALL-PRODUCTIVITY ONE	12.91	TASKS/MAN-DAY	
COMPLETION TIME TWO	498.00	DAYS	
TOTAL EFFORT TWO	1,843.48	MAN-DAYS	
QA EFFORT TWO	440.19	MAN-DAYS	.24
DEVELOP EFFORT TWO	860.73	MAN-DAYS	.47
REWORK EFFORT TWO	262.68	MAN-DAYS	.14
TESTING EFFORT TWO	231.88	MAN-DAYS	.13
TRAINING EFFORT TWO	47.98	MAN-DAYS	.03
OVERALL-PRODUCTIVITY TWO	13.24	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	6.34	MEN	
NET TRANSFERS 1 TO 2	- 6.34	MEN	
TOTAL EFFORT - BOTH	3,733.06	MAN-DAYS	

Figure 56. Simulation 13--Statistical Results

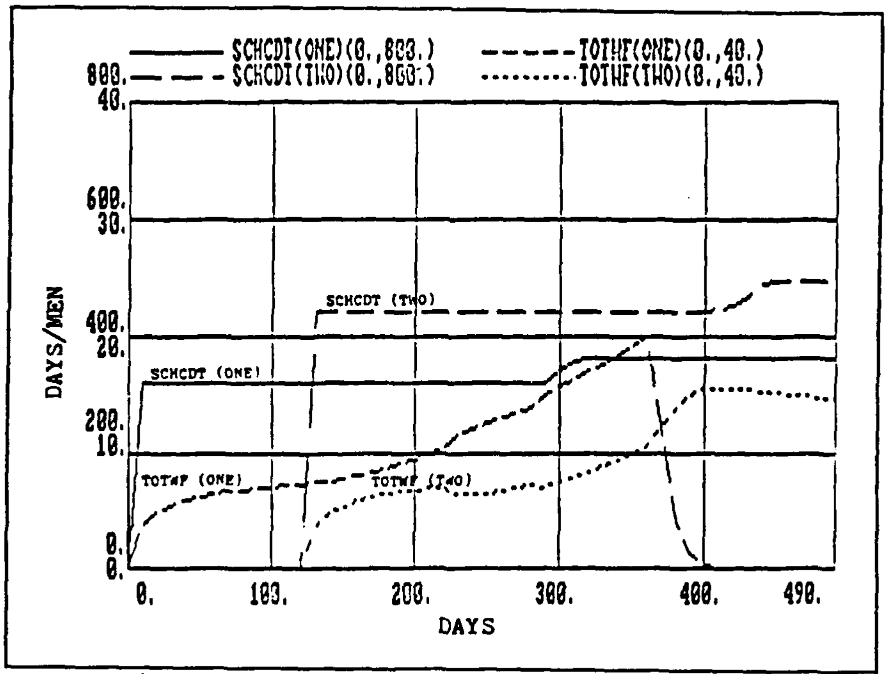


Figure 57. Simulation 13--Graph 1

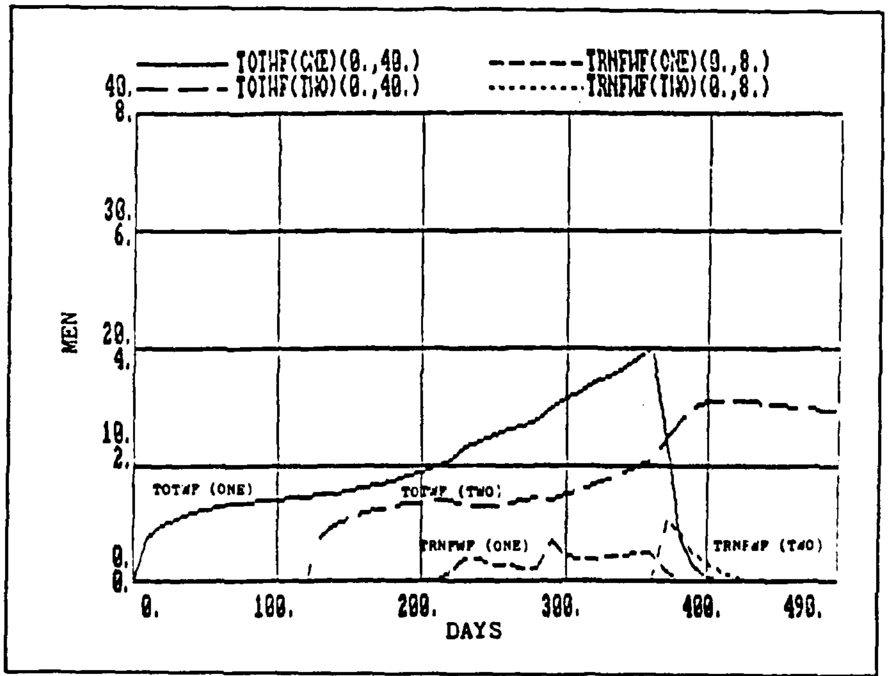


Figure 58. Simulation 13--Graph 2

14. Summary

This set of experiments supports comparisons of costs in simulations in which the project starting first has priority. In-depth analysis of each simulation is of interest to the manager wishing to understand in more detail the complexities of software project management. Following is a brief analysis of two of the simulations in this experiment set.

Simulation three resulted in costs higher than average for this experiment set. In this simulation, the project which will have priority is determined by the model as a function of which project's indicated completion date is farthest from its scheduled completion date. That project in the most trouble, i.e., whose indicated completion date is farthest from its scheduled completion date, will receive transfers. This scenario causes an increase in the number of transfers over the baseline results as priority is continually reassigned back and forth between projects. Additional transfers cause increased training and assimilation time and decrease overall productivity. This in turn causes a greater expenditure of effort, resulting in the increased costs seen in this simulation.

One of the most interesting results of this experiment set was attained when the way in which the workforce ceiling was allocated was changed. This change

was effected in simulation four. Instead of each project being allocated 50 percent of new hires, up to the workforce ceiling for the organization, the project having priority, project one, is allowed to hire what it wants up to the ceiling. If the ceiling is not reached, project two can then hire up to the ceiling. Project two, therefore, is unable to hire in the numbers it would like. This causes project two to rely on transfers from project one, after project one has completed. This increased number of transfers relatively late in project two's development causes decreased productivity and increased costs.

These brief analyses provide the reader with some insight into how different management decisions can affect the costs of developing software projects in a multiproject environment. As in experiment set one, a more detailed analysis of these results is an appropriate area for follow-on research.

E. EXPERIMENT SET THREE

The third set of experiments involved simulations run when the project starting last had priority. As illustrated in Figure 17, costs were at a low point when the project having priority, project one, began 100 days after the project without priority. The actual minimum cost appears to be at time 300 but running simulations with this great a disparity in start dates would minimize the effects of the overlap mechanism. In each of the follow-on simulations run

under this scenario, the start date of the first project was set to 100. In all other ways, this set of experiments is identical to those run in experiment set two. For ease in reading, the descriptions of the simulations are repeated here. Recall that other parameters of note which remained unchanged throughout this scenario, unless otherwise indicated, include the project priority and the workforce ceiling allocation policy. Table 2 provides a summary of the simulations run in this set of experiments. These results are graphically presented in Figure 59.

1. Baseline

The first simulation presented is the "baseline" simulation in which project one has higher priority, project one started 100 days after project two, the workforce ceiling allocation policy is 50:50, and the ceiling on the total workforce is 30. This simulation provides a basis for comparisons with others within this experiment set. Figures 60, 61, and 62 pertain.

2. TRPY11

In this simulation, the priority of the projects (TRPY11) was switched (from TRPY11 = 1 to TRYP11 = 0). In the default, project one has priority. In this simulation, project two was given priority and as such all transfers would occur in the direction of project one to project two until project two completes. Results from this run are shown in Figures 63, 64, and 65.

TABLE 2

RESULTS FROM EXPERIMENT SET THREE SIMULATIONS

	Independent Variable	Cost (Man-days)	Schedule (Days)	Transfers 2 to 1	Transfers 1 to 2
1	BASELINE	3790.05	440.50	-3.28	3.28
2	TRPY11	3691.37	488.50	7.61	-7.61
3	PRTYSW	3951.43	465.00	13.99	-13.99
4	POLCY1	3841.57	440.50	-4.62	4.62
5	TAGRSV	3788.37	442.00	-3.16	3.16
6	T2T1F2 T1T2F2	3790.23	440.50	-3.28	3.28
7	TB2T11 TB1T21	3790.05	440.50	-3.28	3.28
8	TC2T11 TC1T21	3952.07	456.50	-3.80	3.80
9	FORGETa	3940.73	451.50	-3.73	3.73
10	FORGETb	3746.54	431.00	6.38	-6.38
11	TMP1R2 TMP1R1	3790.10	440.50	-3.28	3.28
12	TWRL2T1a TWRL1T2a	3710.61	446.00	20.12	-20.12
13	TWRL2T1b WRL1T2b	3782.80	467.00	11.12	-11.12

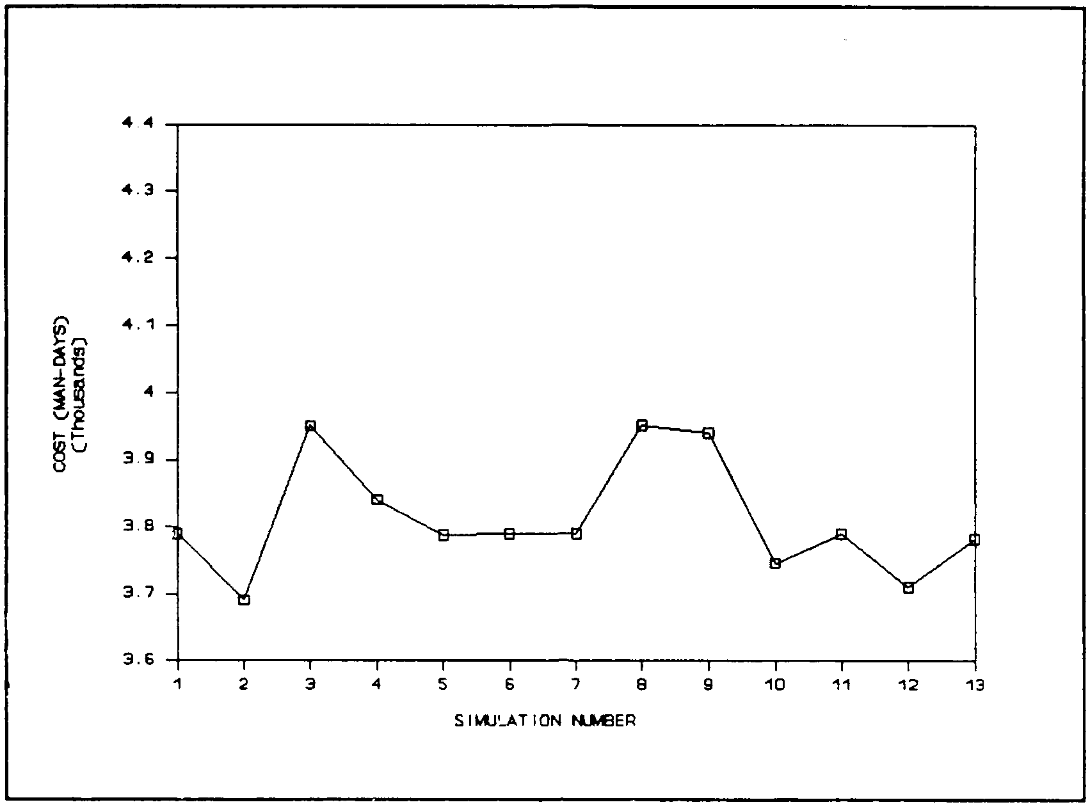


Figure 59. Graphic Results of Experiment Set Three

3. PRTYSW

The third simulation in this set involved changing the way in which priority is determined. Instead of a single project always having priority (PRTYSW = 1), as determined exogenously by management, the priority in this simulation is determined dynamically (PRTYSW = 0). This is comparable to the conditions under which the first five simulations in experiment set one were run. Results from this simulation are shown in Figures 66, 67, and 68.

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	414.50	DAYS	
TOTAL EFFORT ONE	1,845.33	MAN-DAYS	
QA EFFORT ONE	421.53	MAN-DAYS	.23
DEVELOP EFFORT ONE	884.84	MAN-DAYS	.48
REWORK EFFORT ONE	265.80	MAN-DAYS	.14
TESTING EFFORT ONE	248.48	MAN-DAYS	.13
TRAINING EFFORT ONE	24.68	MAN-DAYS	.01
OVERALL-PRODUCTIVITY ONE	13.22	TASKS/MAN-DAY	
COMPLETION TIME TWO	440.50	DAYS	
TOTAL EFFORT TWO	1,944.72	MAN-DAYS	
QA EFFORT TWO	500.88	MAN-DAYS	.26
DEVELOP EFFORT TWO	875.78	MAN-DAYS	.45
REWORK EFFORT TWO	257.95	MAN-DAYS	.13
TESTING EFFORT TWO	260.48	MAN-DAYS	.13
TRAINING EFFORT TWO	49.64	MAN-DAYS	.03
OVERALL-PRODUCTIVITY TWO	12.55	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 3.28	MEN	
NET TRANSFERS 1 TO 2	3.28	MEN	
TOTAL EFFORT - BOTH	3,790.05	MAN-DAYS	

Figure 60. Simulation 1--Statistical Results

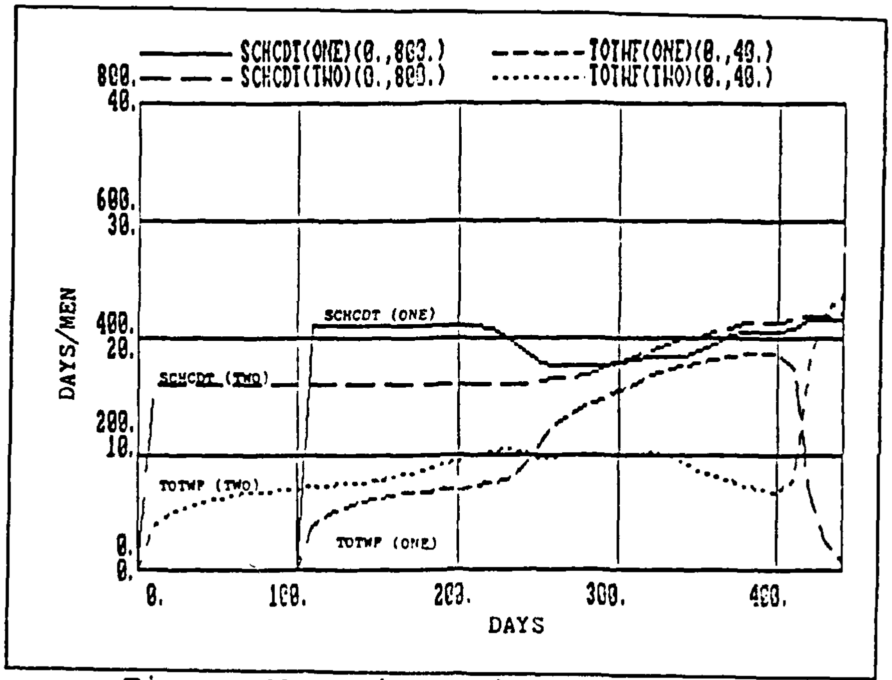


Figure 61. Simulation 1--Graph 1

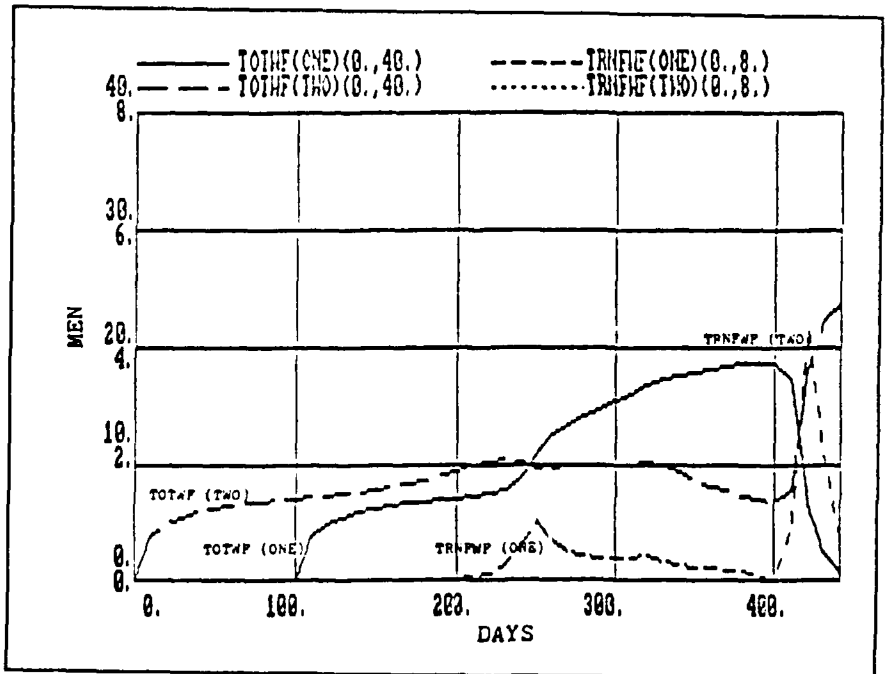


Figure 62. Simulation 1--Graph 2

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	488.50	DAYS	
TOTAL EFFORT ONE	1,838.67	MAN-DAYS	
QA EFFORT ONE	412.70	MAN-DAYS	.22
DEVELOP EFFORT ONE	886.90	MAN-DAYS	.48
REWORK EFFORT ONE	265.44	MAN-DAYS	.14
TESTING EFFORT ONE	247.70	MAN-DAYS	.13
TRAINING EFFORT ONE	25.93	MAN-DAYS	.01
OVERALL-PRODUCTIVITY ONE	13.27	TASKS/MAN-DAY	
COMPLETION TIME TWO	370.00	DAYS	
TOTAL EFFORT TWO	1,852.70	MAN-DAYS	
QA EFFORT TWO	452.16	MAN-DAYS	.24
DEVELOP EFFORT TWO	861.86	MAN-DAYS	.47
REWORK EFFORT TWO	260.14	MAN-DAYS	.14
TESTING EFFORT TWO	236.08	MAN-DAYS	.13
TRAINING EFFORT TWO	42.45	MAN-DAYS	.02
OVERALL-PRODUCTIVITY TWO	13.17	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	7.61	MEN	
NET TRANSFERS 1 TO 2	- 7.61	MEN	
TOTAL EFFORT - BOTH	3,691.37	MAN-DAYS	

Figure 63. Simulation 2--Statistical Results

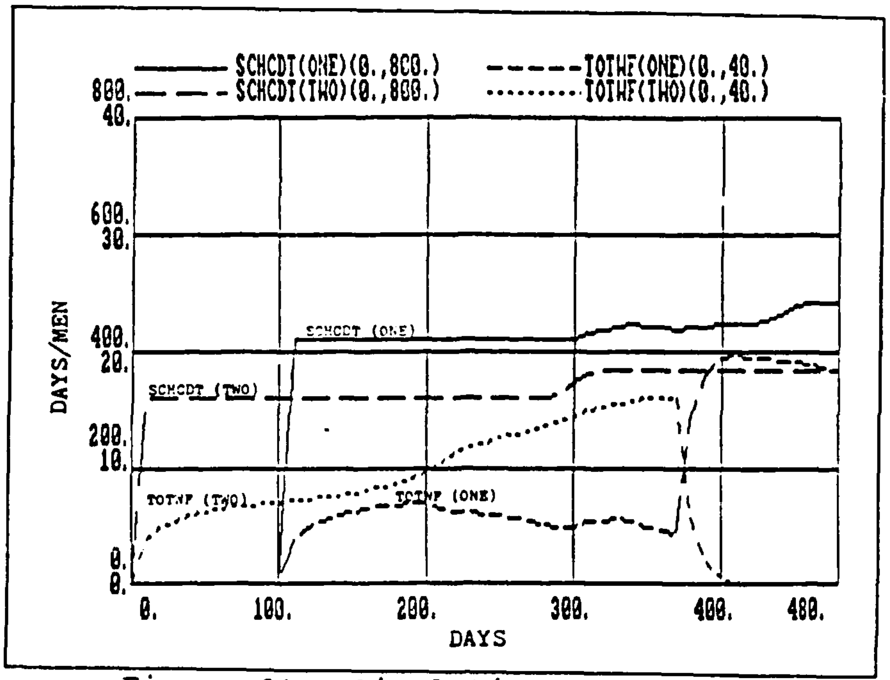


Figure 64. Simulation 2--Graph 1

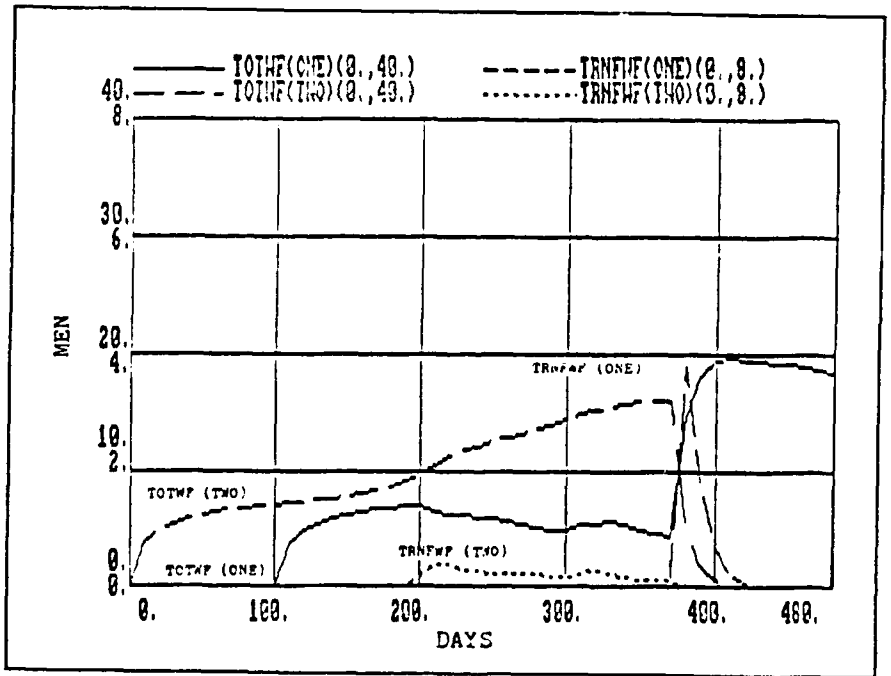


Figure 65. Simulation 2--Graph 2

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	465.00	DAYS	
TOTAL EFFORT ONE	2,028.94	MAN-DAYS	
QA EFFORT ONE	517.28	MAN-DAYS	.25
DEVELOP EFFORT ONE	933.40	MAN-DAYS	.46
REWORK EFFORT ONE	268.56	MAN-DAYS	.13
TESTING EFFORT ONE	285.46	MAN-DAYS	.14
TRAINING EFFORT ONE	24.24	MAN-DAYS	.01
OVERALL-PRODUCTIVITY ONE	12.03	TASKS/MAN-DAY	
COMPLETION TIME TWO	399.00	DAYS	
TOTAL EFFORT TWO	1,922.49	MAN-DAYS	
QA EFFORT TWO	494.60	MAN-DAYS	.26
DEVELOP EFFORT TWO	882.91	MAN-DAYS	.46
REWORK EFFORT TWO	262.31	MAN-DAYS	.14
TESTING EFFORT TWO	240.34	MAN-DAYS	.13
TRAINING EFFORT TWO	42.32	MAN-DAYS	.02
OVERALL-PRODUCTIVITY TWO	12.69	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	13.99	MEN	
NET TRANSFERS 1 TO 2	- 13.99	MEN	
TOTAL EFFORT - BOTH	3,951.43	MAN-DAYS	

Figure 66. Simulation 3--Statistical Results

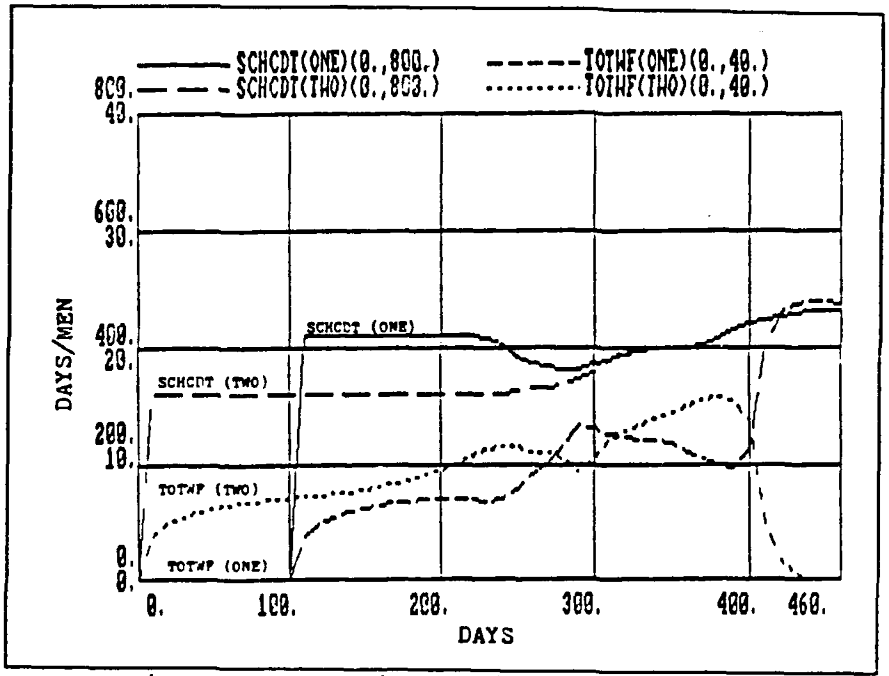


Figure 67. Simulation 3--Graph 1

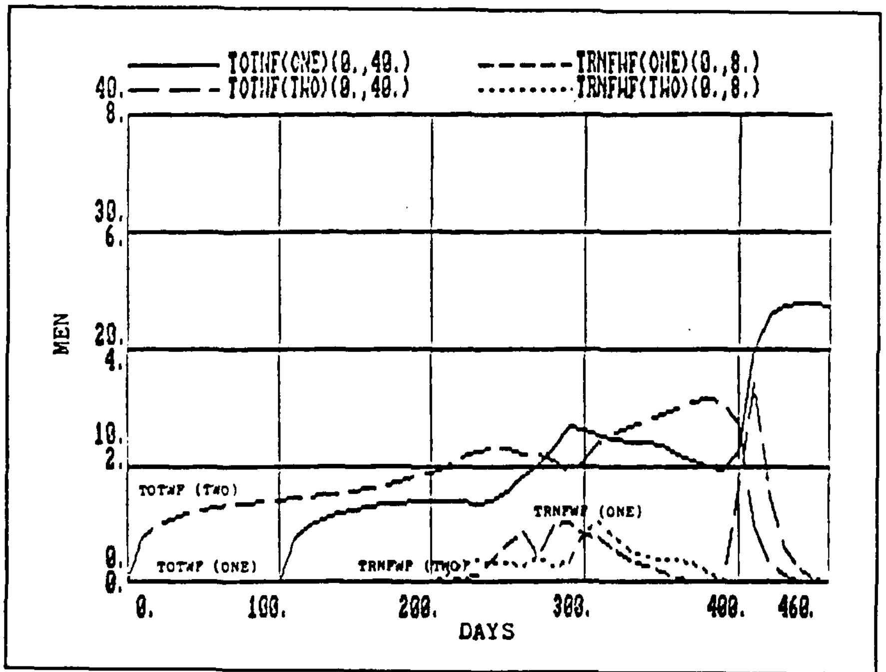


Figure 68. Simulation 3--Graph 2

4. POLCY1

In this simulation, the variable changed was that which affects the management policy regarding how the work-force ceiling is allocated (POLCY1). In lieu of having a 50:50 allocation (POLCY1 = 1), in which each project gets 50 percent of the ceiling, the policy was changed (POLCY1 = 0). This simulation represents the effects of an allocation policy in which the project which has priority is allowed to hire in whatever numbers it needs up to the ceiling; the second project can hire only the workforce representing the difference between what the first project has hired and the organizational ceiling. Of note is the fact that in either case the default ceiling of 30 is sufficient for both projects to complete on time without undue pressure resulting from this ceiling if the workforce is acquired early enough to allow for assimilation. Results from this simulation are presented in Figures 69, 70, and 71.

5. TAGRSV

In the fifth simulation, the variable affecting the aggressiveness of the manager and his willingness to change the workforce assuming transfers will occur (TAGRSV) is changed. It is decreased from one to .5. The consequence of this change is to simulate a manager who is more willing to transfer people from the other project (project two). Results from this simulation are shown in Figures 72, 73, and 74.

PROJECT STATISTICS:			
			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	413.50	DAYS	
TOTAL EFFORT ONE	1,883.78	MAN-DAYS	
QA EFFORT ONE	429.59	MAN-DAYS	.23
DEVELOP EFFORT ONE	896.17	MAN-DAYS	.48
REWORK EFFORT ONE	269.52	MAN-DAYS	.14
TESTING EFFORT ONE	257.30	MAN-DAYS	.14
TRAINING EFFORT ONE	31.20	MAN-DAYS	.02
OVERALL-PRODUCTIVITY ONE	12.95	TASKS/MAN-DAY	
COMPLETION TIME TWO	440.50	DAYS	
TOTAL EFFORT TWO	1,957.79	MAN-DAYS	
QA EFFORT TWO	496.23	MAN-DAYS	.25
DEVELOP EFFORT TWO	875.58	MAN-DAYS	.45
REWORK EFFORT TWO	257.68	MAN-DAYS	.13
TESTING EFFORT TWO	274.57	MAN-DAYS	.14
TRAINING EFFORT TWO	53.73	MAN-DAYS	.03
OVERALL-PRODUCTIVITY TWO	12.46	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 4.62	MEN	
NET TRANSFERS 1 TO 2	4.62	MEN	
TOTAL EFFORT - BOTH	3,841.57	MAN-DAYS	

Figure 69. Simulation 4--Statistical Results

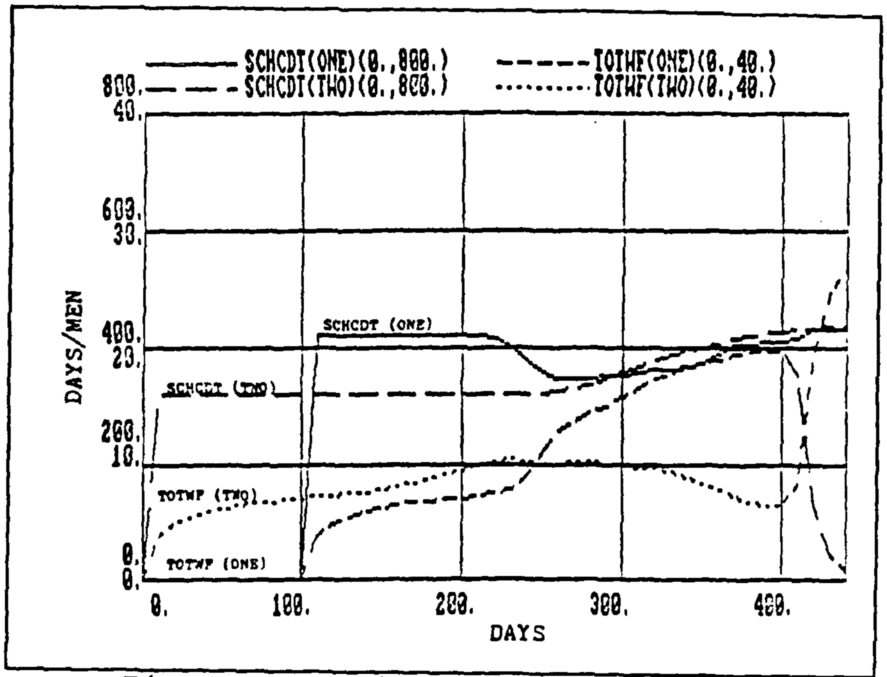


Figure 70. Simulation 4--Graph 1

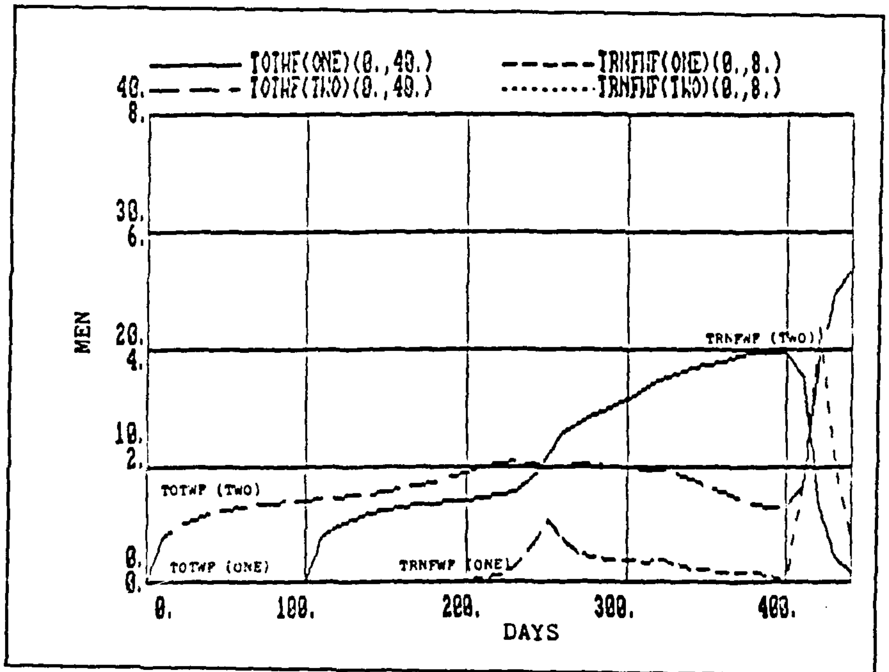


Figure 71. Simulation 4--Graph 2

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	414.00	DAYS	
TOTAL EFFORT ONE	1,847.91	MAN-DAYS	
QA EFFORT ONE	421.56	MAN-DAYS	.23
DEVELOP EFFORT ONE	884.92	MAN-DAYS	.48
REWORK EFFORT ONE	265.72	MAN-DAYS	.14
TESTING EFFORT ONE	251.03	MAN-DAYS	.14
TRAINING EFFORT ONE	24.68	MAN-DAYS	.01
OVERALL-PRODUCTIVITY ONE	13.20	TASKS/MAN-DAY	
COMPLETION TIME TWO	442.00	DAYS	
TOTAL EFFORT TWO	1,940.46	MAN-DAYS	
QA EFFORT TWO	500.66	MAN-DAYS	.26
DEVELOP EFFORT TWO	875.04	MAN-DAYS	.45
REWORK EFFORT TWO	257.82	MAN-DAYS	.13
TESTING EFFORT TWO	257.30	MAN-DAYS	.13
TRAINING EFFORT TWO	49.63	MAN-DAYS	.03
OVERALL-PRODUCTIVITY TWO	12.57	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 3.16	MEN	
NET TRANSFERS 1 TO 2	3.16	MEN	
TOTAL EFFORT - BOTH	3,788.37	MAN-DAYS	

Figure 72. Simulation 5--Statistical Results

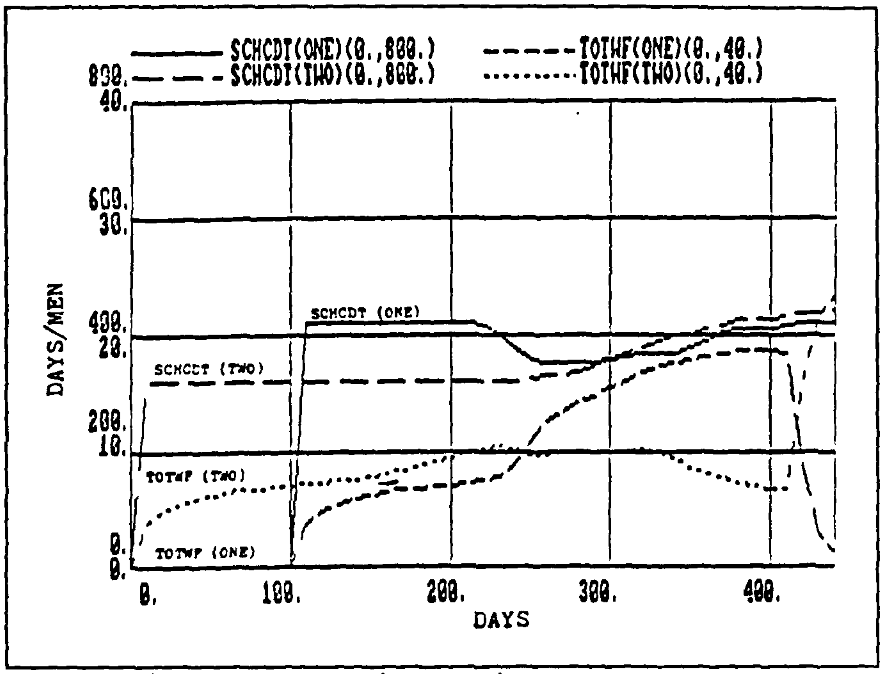


Figure 73. Simulation 5--Graph 1

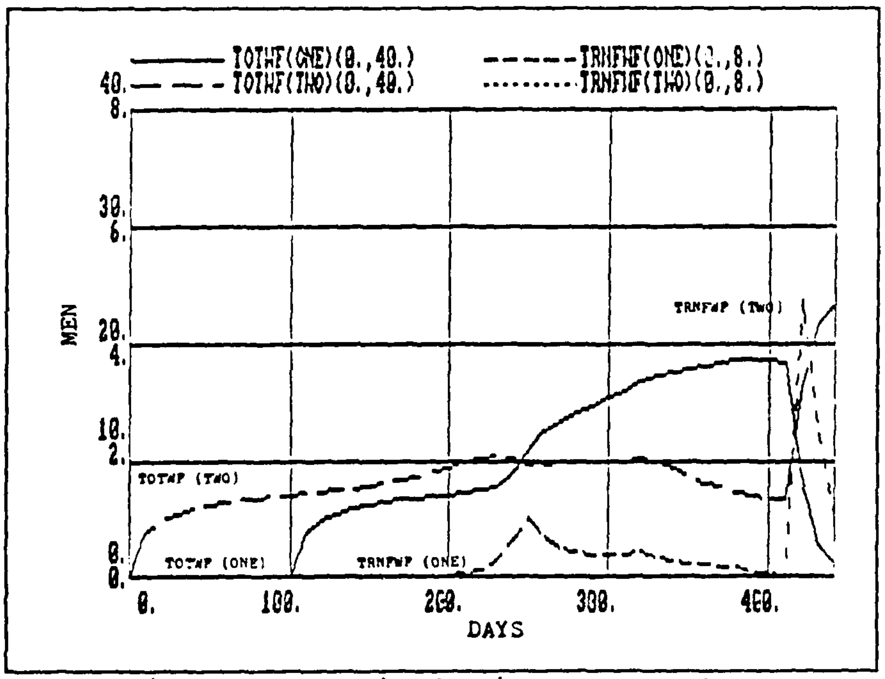


Figure 74. Simulation 5--Graph 2

6. T2T1F2 and T1T2F2

Similar to the fifth simulation, the effect of the change in this run of the model was to simulate a manager who is more willing to transfer workforce by force from the other project to meet his manpower needs. These variables (T2T1F2 and T1T2F2) model willingness to force transfers as a function of the percent reported completed of the second project. They are originally set to values which indicate an unwillingness on the manager's part to force transfers from a project just beginning. This is because the manager realizes the importance of not disrupting a project in its early stages, when it is building on its core team. Thus even though project one has priority, its manager would not be willing to force transfers from project two because he knew it was in its "building up" stage. In this case both the variable affecting project one and its equivalent (T2T1F2 and T2T1F2) were increased in value such that this period of non-disruption is denied. The default values of these variables are 0/.2/.5/.9/1/1 while the new values as used in this simulation are 1/1/1/1/1/1. The reader is reminded that values such as these represent table functions in the Dynamo language. In table functions each number is associated with the occurrence of an event. For instance, in this example, a manager would have "0" willingness to force transfers when project two was reporting zero percent completion. A more detailed discussion of the table

function and its application, while beyond the scope of this work, can be found in Alexander Pugh's book, Dynamo User's Manual. However, in several cases these types of values are included in the description of the simulation to enable duplication of these simulations in follow-up research. Results from this simulation are given in Figures 75, 76, and 77.

7. TB2T11 and TB1T21

In this simulation another variable and its equivalent (TB2T11 and TB1T21) were changed. These variables are used in conjunction with those described in simulation eight to ascertain the overall fraction of his workforce the manager can be forced to transfer. These variables provide input to this fraction as a function of the percent reported completed of the second project. In the default situation project one will not force transfers from project two at all until it is at least ten percent complete. The contribution of these two variables is zero until this time causing a zero fraction of the workforce to be forcibly transferred. The change effected in this simulation was such that these variables no longer had any affect on the overall fraction of the workforce to be transferred--a simulation which could be used to ascertain if the concept which these variables model is an actual concern of managers. If the change does not produce significantly different results from the baseline case, then

PROJECT STATISTICS:			
			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	414.50	DAYS	
TOTAL EFFORT ONE	1,845.28	MAN-DAYS	
QA EFFORT ONE	421.44	MAN-DAYS	.23
DEVELOP EFFORT ONE	884.82	MAN-DAYS	.48
REWORK EFFORT ONE	265.80	MAN-DAYS	.14
TESTING EFFORT ONE	248.54	MAN-DAYS	.13
TRAINING EFFORT ONE	24.68	MAN-DAYS	.01
OVERALL-PRODUCTIVITY ONE	13.22	TASKS/MAN-DAY	
COMPLETION TIME TWO	440.50	DAYS	
TOTAL EFFORT TWO	1,944.95	MAN-DAYS	
QA EFFORT TWO	500.95	MAN-DAYS	.26
DEVELOP EFFORT TWO	875.72	MAN-DAYS	.45
REWORK EFFORT TWO	257.96	MAN-DAYS	.13
TESTING EFFORT TWO	260.62	MAN-DAYS	.13
TRAINING EFFORT TWO	49.70	MAN-DAYS	.03
OVERALL-PRODUCTIVITY TWO	12.55	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 3.28	MEN	
NET TRANSFERS 1 TO 2	3.28	MEN	
TOTAL EFFORT - BOTH	3,790.23	MAN-DAYS	

Figure 75. Simulation 6--Statistical Results

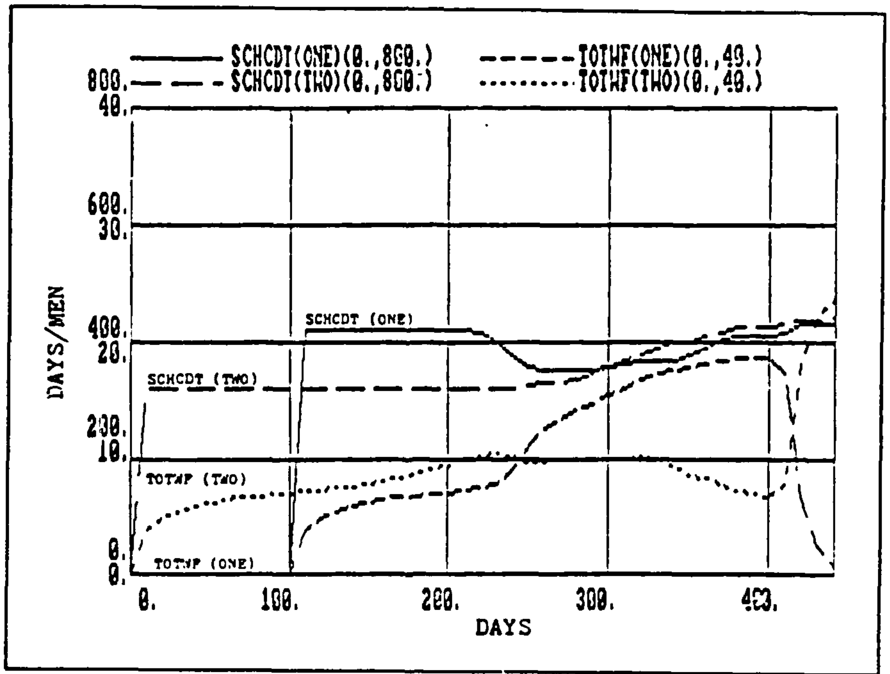


Figure 76. Simulation 6--Graph 1

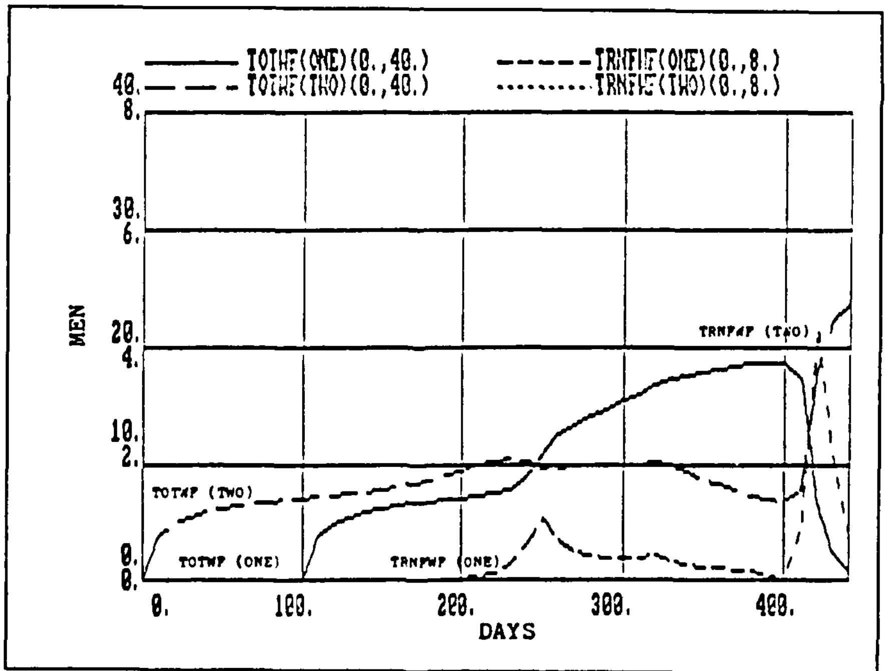


Figure 77. Simulation 6--Graph 2

this variable has little effect on the manager's decision. The default values of these variables are 0/.2/.5/.9/1/1 and the values on which this simulation were based are 1/1/1/1/1/1. Figures 78, 79, and 80 illustrate the results.

8. TC2T11 and TC1T21

In this simulation the variable affecting the fraction of his workforce a manager can be forced to transfer as a function of the cumulative recentness of transfers and its equivalent in the other project are increased (TC2T11 and TC1T21). These variables are used in conjunction with those described in simulation seven to ascertain the overall fraction of his workforce the manager can be forced to transfer. The default values of these variables (11 values ranging from .5 to zero) are such that if a manager has recently transferred out a large portion of his workforce he will not be forced to transfer any more individuals at the present time. These values were increased (all 11 values are now equal to the value one). The change effected in this simulation was such that these variables no longer had any affect on the overall fraction of the workforce to be transferred--a simulation which could be used to ascertain if the concept which these variables model is an actual concern of managers. If the change does not produce significantly different results from the baseline case than this variable has little effect on the manager's decision. Figures 81, 82, and 83 pertain.

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	414.50	DAYS	
TOTAL EFFORT ONE	1,845.33	MAN-DAYS	
QA EFFORT ONE	421.53	MAN-DAYS	.23
DEVELOP EFFORT ONE	884.84	MAN-DAYS	.48
REWORK EFFORT ONE	265.80	MAN-DAYS	.14
TESTING EFFORT ONE	248.48	MAN-DAYS	.13
TRAINING EFFORT ONE	24.68	MAN-DAYS	.01
OVERALL-PRODUCTIVITY ONE	13.22	TASKS/MAN-DAY	
COMPLETION TIME TWO	440.50	DAYS	
TOTAL EFFORT TWO	1,944.72	MAN-DAYS	
QA EFFORT TWO	500.88	MAN-DAYS	.26
DEVELOP EFFORT TWO	875.78	MAN-DAYS	.45
REWORK EFFORT TWO	257.95	MAN-DAYS	.13
TESTING EFFORT TWO	260.48	MAN-DAYS	.13
TRAINING EFFORT TWO	49.64	MAN-DAYS	.03
OVERALL-PRODUCTIVITY TWO	12.55	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 3.28	MEN	
NET TRANSFERS 1 TO 2	3.28	MEN	
TOTAL EFFORT - BOTH	3,790.05	MAN-DAYS	

Figure 78. Simulation 7--Statistical Results

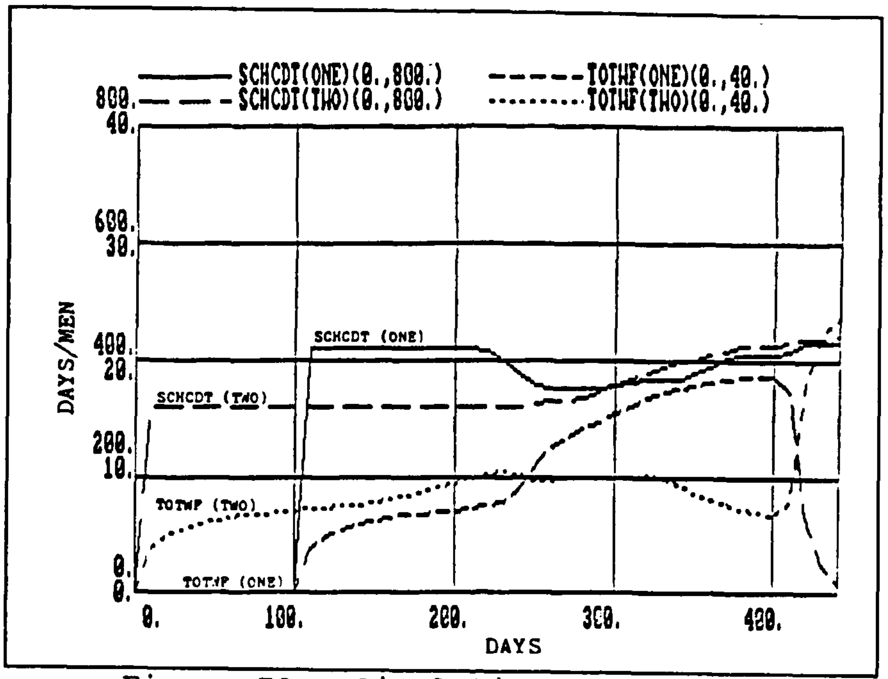


Figure 79. Simulation 7--Graph 1

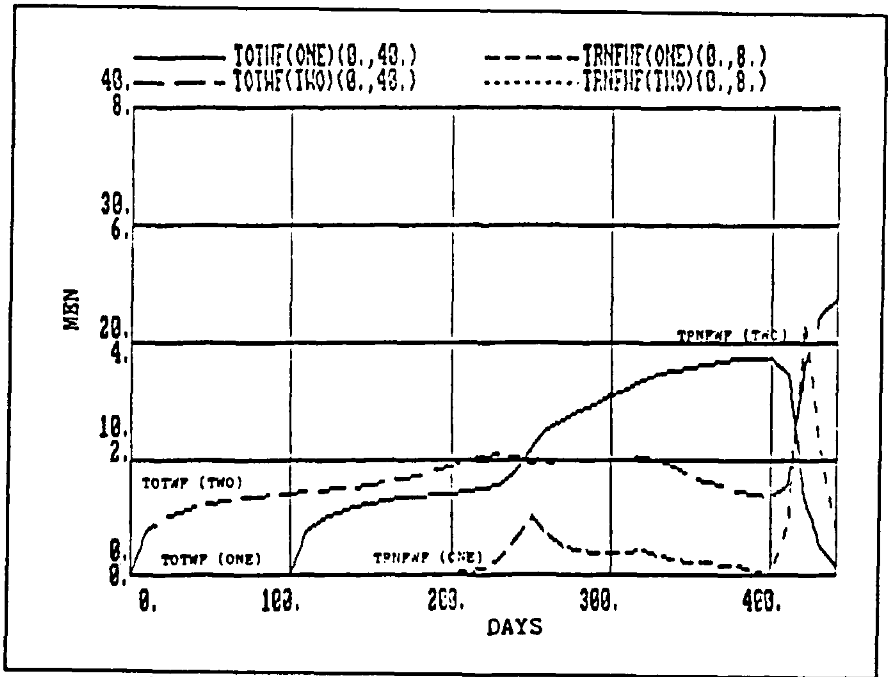


Figure 80. Simulation 7--Graph 2

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	403.00	DAYS	
TOTAL EFFORT ONE	1,924.12	MAN-DAYS	
QA EFFORT ONE	431.44	MAN-DAYS	.22
DEVELOP EFFORT ONE	919.38	MAN-DAYS	.48
REWORK EFFORT ONE	275.75	MAN-DAYS	.14
TESTING EFFORT ONE	273.19	MAN-DAYS	.14
TRAINING EFFORT ONE	24.34	MAN-DAYS	.01
OVERALL-PRODUCTIVITY ONE	12.68	TASKS/MAN-DAY	
COMPLETION TIME TWO	456.50	DAYS	
TOTAL EFFORT TWO	2,027.95	MAN-DAYS	
QA EFFORT TWO	537.95	MAN-DAYS	.27
DEVELOP EFFORT TWO	919.06	MAN-DAYS	.45
REWORK EFFORT TWO	262.08	MAN-DAYS	.13
TESTING EFFORT TWO	263.22	MAN-DAYS	.13
TRAINING EFFORT TWO	45.64	MAN-DAYS	.02
OVERALL-PRODUCTIVITY TWO	12.03	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 3.80	MEN	
NET TRANSFERS 1 TO 2	3.80	MEN	
TOTAL EFFORT - BOTH	3,952.07	MAN-DAYS	

Figure 81. Simulation 8--Statistical Results

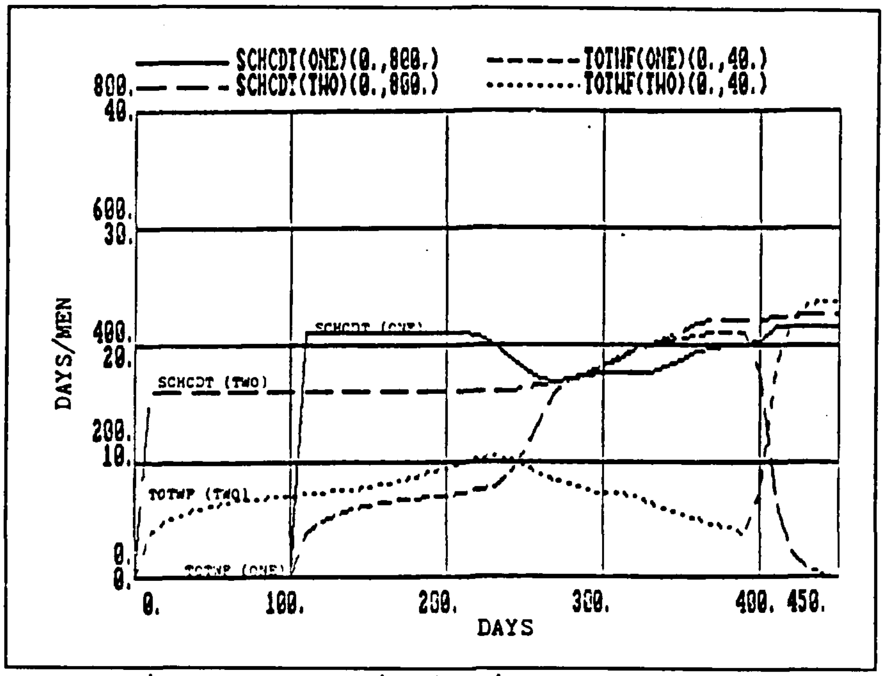


Figure 82. Simulation 8--Graph 1

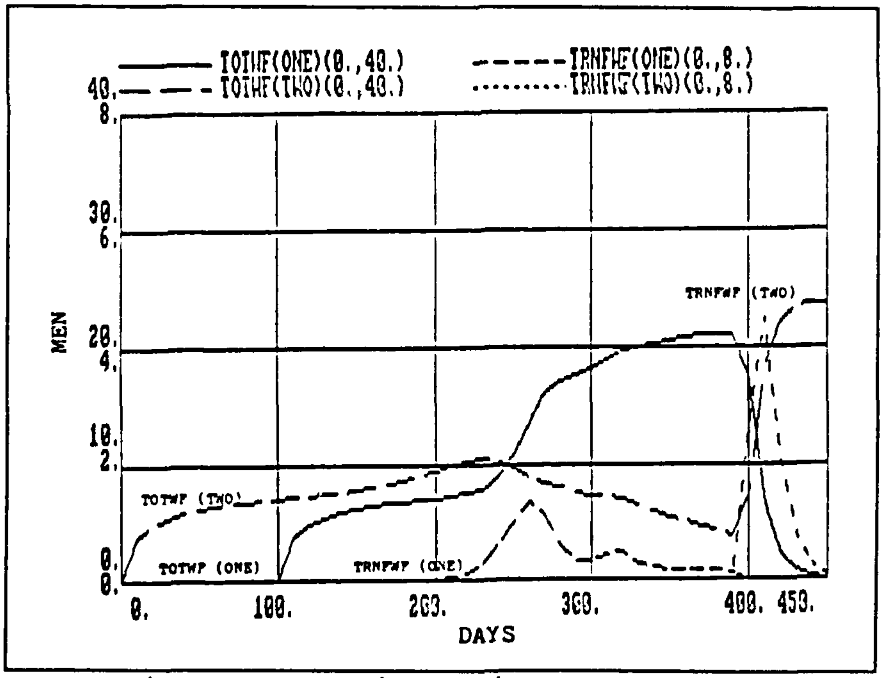


Figure 83. Simulation 8--Graph 2

9. <u>FORGETa</u>

In the ninth simulation, the time it takes a manager to "forget" about recent transfers (FORGET) was decreased from the default value of 60 to 30. This variable affects the willingness of that manager to transfer more of his workforce. The lower the value of this variable, the more apt the manager is to allow transfers as he has already forgotten about relatively recent transfers. Results are provided in Figures 84, 85, and 86.

10. <u>FORGETb</u>

The amount of time it takes a manager to "forget" about recent transfers (FORGET) was increased over the default value from 60 to 120. More information is provided in the description of simulation nine. See the results in Figures 87, 88, and 89.

11. <u>TMP1R2 and TMP1R1</u>

In this experiment, the impact of the hiring ceiling on the willingness to force transfers from a project because its workforce could be replenished is changed as is its equiva-lent in the other project (TMP1R2 and TMP1R1). This change allows simulation of a situation in which the ceiling has less of an impact on the final decision than in the baseline case. Note that the result of the change is <u>less</u> of an impact although the default values of these variables were increased from 0/.5/.75/.9/.975/1/1/1/1/1/1 to all

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	403.50	DAYS	
TOTAL EFFORT ONE	1,932.46	MAN-DAYS	
QA EFFORT ONE	431.22	MAN-DAYS	.22
DEVELOP EFFORT ONE	922.17	MAN-DAYS	.48
REWORK EFFORT ONE	276.22	MAN-DAYS	.14
TESTING EFFORT ONE	278.50	MAN-DAYS	.14
TRAINING EFFORT ONE	24.34	MAN-DAYS	.01
OVERALL-PRODUCTIVITY ONE	12.63	TASKS/MAN-DAY	
COMPLETION TIME TWO	451.50	DAYS	
TOTAL EFFORT TWO	2,008.27	MAN-DAYS	
QA EFFORT TWO	523.42	MAN-DAYS	.26
DEVELOP EFFORT TWO	906.33	MAN-DAYS	.45
REWORK EFFORT TWO	260.13	MAN-DAYS	.13
TESTING EFFORT TWO	272.78	MAN-DAYS	.14
TRAINING EFFORT TWO	45.59	MAN-DAYS	.02
OVERALL-PRODUCTIVITY TWO	12.15	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 3.73	MEN	
NET TRANSFERS 1 TO 2	3.73	MEN	
TOTAL EFFORT - BOTH	3,940.73	MAN-DAYS	

Figure 84. Simulation 9--Statistical Results

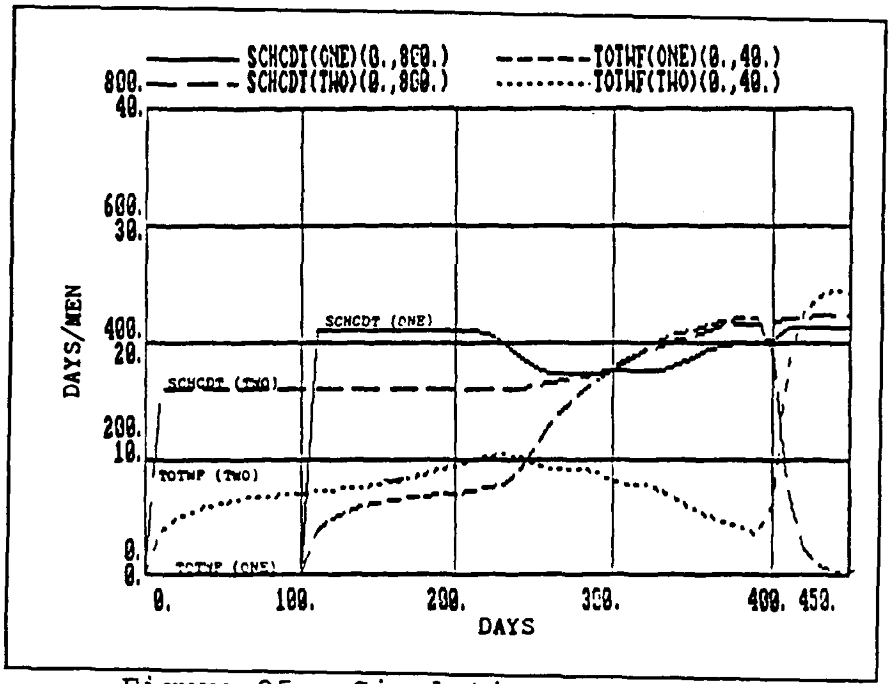


Figure 85. Simulation 9--Graph 1

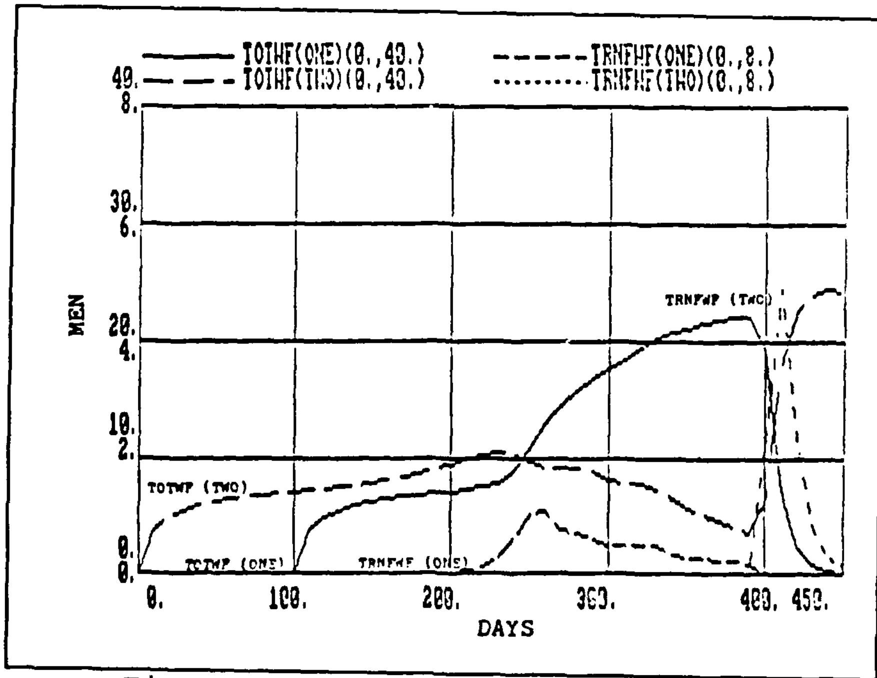


Figure 86. Simulation 9--Graph 2

PROJECT STATISTICS:			
			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	431.00	DAYS	
TOTAL EFFORT ONE	1,812.26	MAN-DAYS	
QA EFFORT ONE	423.73	MAN-DAYS	.23
DEVELOP EFFORT ONE	869.74	MAN-DAYS	.48
REWORK EFFORT ONE	262.12	MAN-DAYS	.14
TESTING EFFORT ONE	229.19	MAN-DAYS	.13
TRAINING EFFORT ONE	27.47	MAN-DAYS	.02
OVERALL-PRODUCTIVITY ONE	13.46	TASKS/MAN-DAY	
COMPLETION TIME TWO	429.50	DAYS	
TOTAL EFFORT TWO	1,934.28	MAN-DAYS	
QA EFFORT TWO	500.57	MAN-DAYS	.26
DEVELOP EFFORT TWO	872.03	MAN-DAYS	.45
REWORK EFFORT TWO	259.70	MAN-DAYS	.13
TESTING EFFORT TWO	241.36	MAN-DAYS	.12
TRAINING EFFORT TWO	60.63	MAN-DAYS	.03
OVERALL-PRODUCTIVITY TWO	12.61	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	6.38	MEN	
NET TRANSFERS 1 TO 2	- 6.38	MEN	
TOTAL EFFORT - BOTH	3,746.54	MAN-DAYS	

Figure 87. Simulation 10--Statistical Results

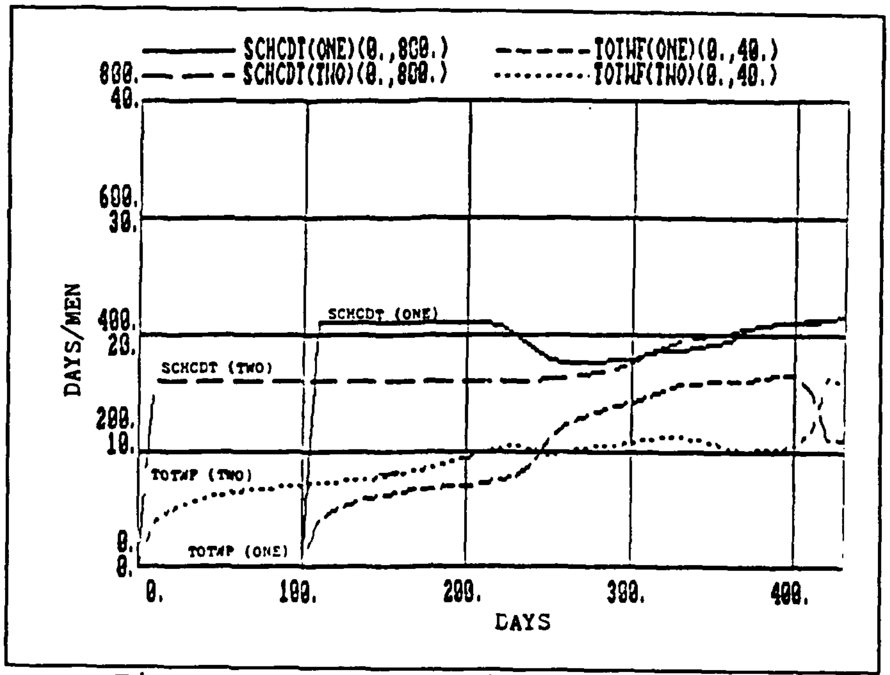


Figure 88. Simulation 10--Graph 1

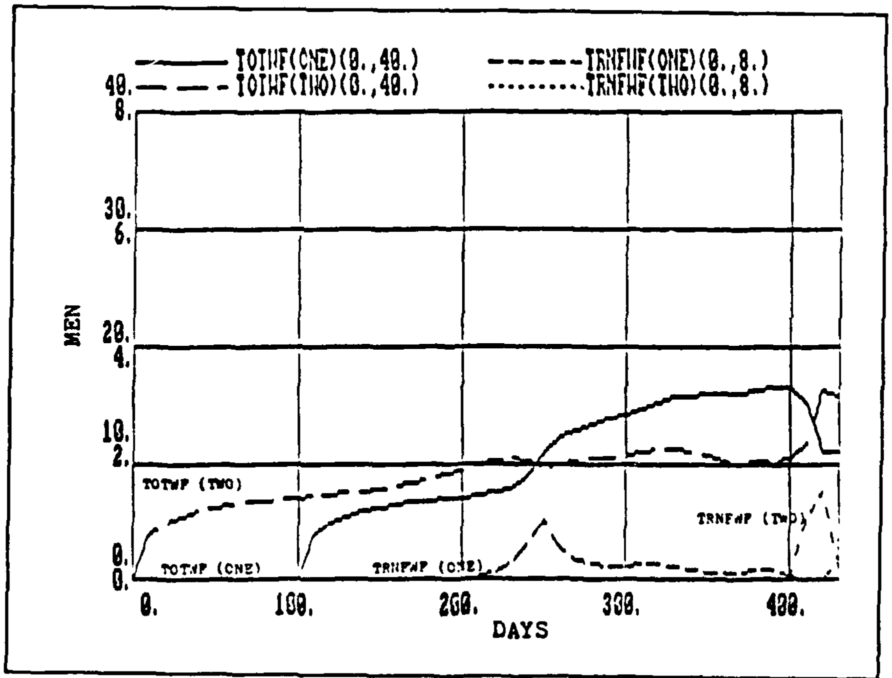


Figure 89. Simulation 10--Graph 2

one's. The results of the simulation are presented in Figures 90, 91, and 92.

12. TWRL2T1a and TWRL1T2a

The manager's willingness to rely on the release of people from a completing project and its equivalent in the other project are the independent variables in this simulation (TWRL2T1 and TWRL1T2). This willingness is a ratio of the time remaining (for the completing project) to the hiring delay; the higher the ratio, the less apt the manager is to wait in the baseline scenario. In this simulation, this willingness was increased, from 1/.5/.25/.1/0/0, the default values, to 1/1/1/1/1/1. This increase simulates a manager who is always willing to rely on release of personnel from the other project regardless of how much longer it has before completion. Figures 93, 94, and 95 provide results.

13. TWRL2T1b and TWRL1T2b

Once again, the manager's willingness to rely on the release of people from a completing project is the independent variable. However, in this case, this willingness was decreased from the default values given in the description of simulation 12 to 0/0/0/0/0/0. This decrease causes the situation in which the manager will never rely on people from the other project based on its completion. Figures 96, 97, and 98 are relevant.

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	414.50	DAYS	
TOTAL EFFORT ONE	1,845.46	MAN-DAYS	
QA EFFORT ONE	421.45	MAN-DAYS	.23
DEVELOP EFFORT ONE	884.99	MAN-DAYS	.48
REWORK EFFORT ONE	265.83	MAN-DAYS	.14
TESTING EFFORT ONE	248.51	MAN-DAYS	.13
TRAINING EFFORT ONE	24.68	MAN-DAYS	.01
OVERALL-PRODUCTIVITY ONE	13.22	TASKS/MAN-DAY	
COMPLETION TIME TWO	440.50	DAYS	
TOTAL EFFORT TWO	1,944.64	MAN-DAYS	
QA EFFORT TWO	500.89	MAN-DAYS	.26
DEVELOP EFFORT TWO	875.79	MAN-DAYS	.45
REWORK EFFORT TWO	257.95	MAN-DAYS	.13
TESTING EFFORT TWO	260.37	MAN-DAYS	.13
TRAINING EFFORT TWO	49.64	MAN-DAYS	.03
OVERALL-PRODUCTIVITY TWO	12.55	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	- 3.28	MEN	
NET TRANSFERS 1 TO 2	3.28	MEN	
TOTAL EFFORT - BOTH	3,790.10	MAN-DAYS	

Figure 90. Simulation 11--Statistical Results

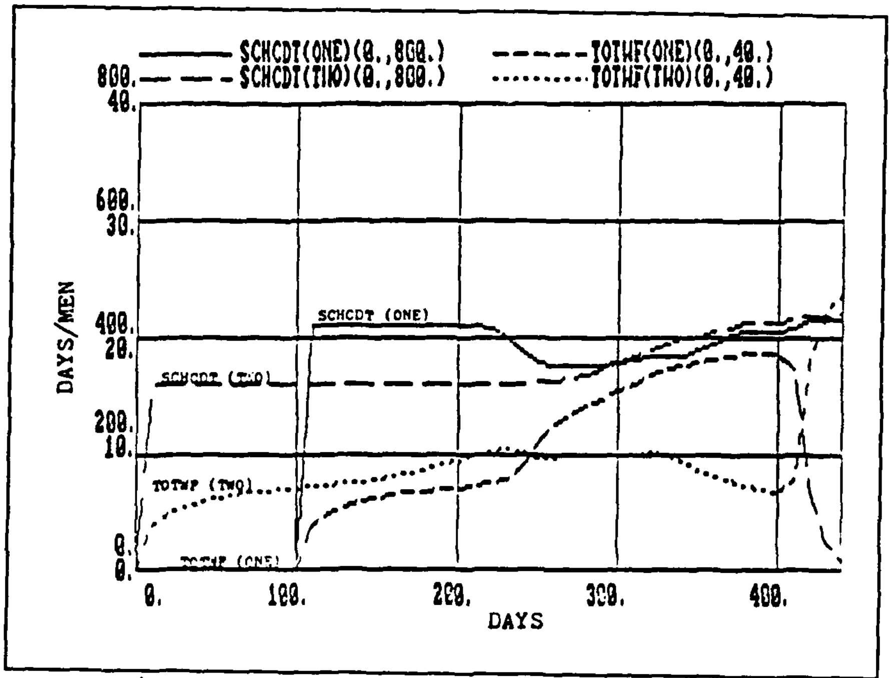


Figure 91. Simulation 11--Graph 1

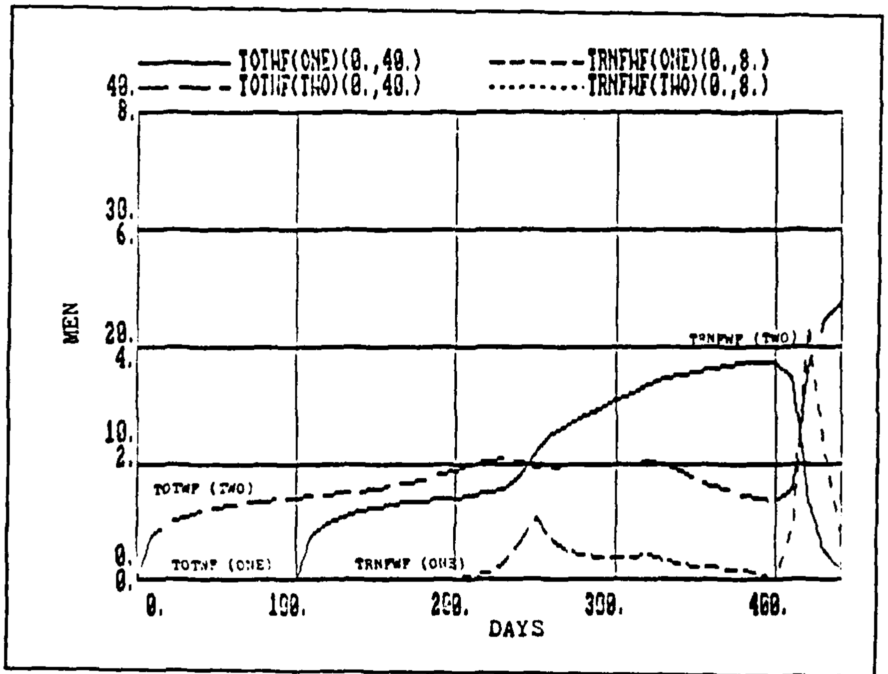


Figure 92. Simulation 11--Graph 2

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	446.00	DAYS	
TOTAL EFFORT ONE	1,791.38	MAN-DAYS	
QA EFFORT ONE	406.51	MAN-DAYS	.23
DEVELOP EFFORT ONE	880.55	MAN-DAYS	.49
REWORK EFFORT ONE	259.40	MAN-DAYS	.14
TESTING EFFORT ONE	244.11	MAN-DAYS	.14
TRAINING EFFORT ONE	.81	MAN-DAYS	.00
OVERALL-PRODUCTIVITY ONE	13.62	TASKS/MAN-DAY	
COMPLETION TIME TWO	439.00	DAYS	
TOTAL EFFORT TWO	1,919.22	MAN-DAYS	
QA EFFORT TWO	494.75	MAN-DAYS	.26
DEVELOP EFFORT TWO	867.90	MAN-DAYS	.45
REWORK EFFORT TWO	258.23	MAN-DAYS	.13
TESTING EFFORT TWO	238.29	MAN-DAYS	.12
TRAINING EFFORT TWO	60.05	MAN-DAYS	.03
OVERALL-PRODUCTIVITY TWO	12.71	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	20.12	MEN	
NET TRANSFERS 1 TO 2	- 20.12	MEN	
TOTAL EFFORT - BOTH	3,710.61	MAN-DAYS	

Figure 93. Simulation 12--Statistical Results

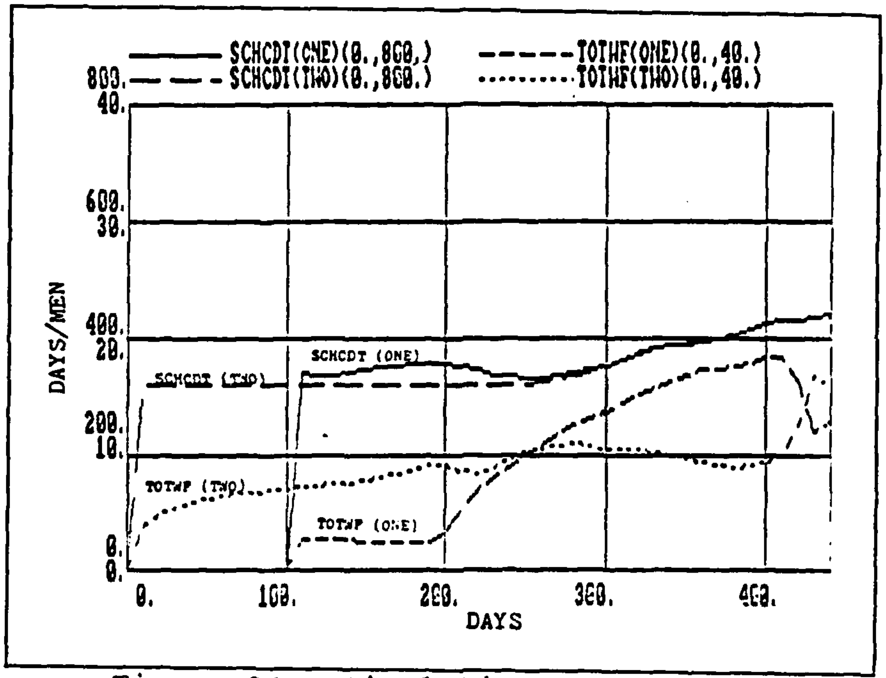


Figure 94. Simulation 12--Graph 1

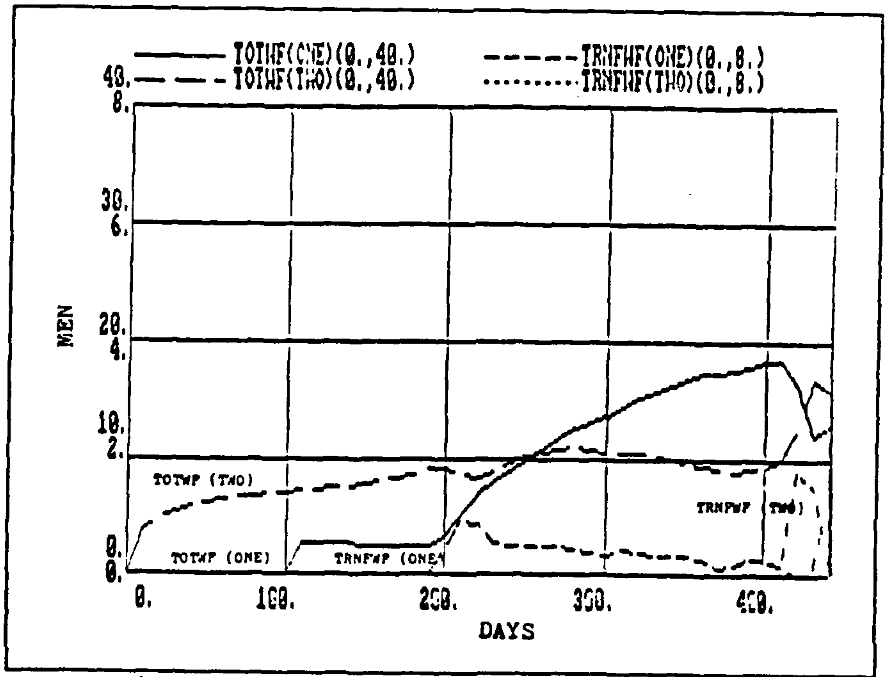


Figure 95. Simulation 12--Graph 2

PROJECT STATISTICS:

			PORTION OF TOTAL EFFORT
COMPLETION TIME ONE	467.00	DAYS	
TOTAL EFFORT ONE	1,847.37	MAN-DAYS	
QA EFFORT ONE	454.38	MAN-DAYS	.25
DEVELOP EFFORT ONE	864.41	MAN-DAYS	.47
REWORK EFFORT ONE	256.28	MAN-DAYS	.14
TESTING EFFORT ONE	238.44	MAN-DAYS	.13
TRAINING EFFORT ONE	33.85	MAN-DAYS	.02
OVERALL-PRODUCTIVITY ONE	13.21	TASKS/MAN-DAY	
COMPLETION TIME TWO	408.50	DAYS	
TOTAL EFFORT TWO	1,935.44	MAN-DAYS	
QA EFFORT TWO	494.27	MAN-DAYS	.26
DEVELOP EFFORT TWO	874.58	MAN-DAYS	.45
REWORK EFFORT TWO	263.04	MAN-DAYS	.14
TESTING EFFORT TWO	234.08	MAN-DAYS	.12
TRAINING EFFORT TWO	69.46	MAN-DAYS	.04
OVERALL-PRODUCTIVITY TWO	12.61	TASKS/MAN-DAY	
NET TRANSFERS 2 TO 1	11.12	MEN	
NET TRANSFERS 1 TO 2	- 11.12	MEN	
TOTAL EFFORT - BOTH	3,782.80	MAN-DAYS	

Figure 96. Simulation 13--Statistical Results

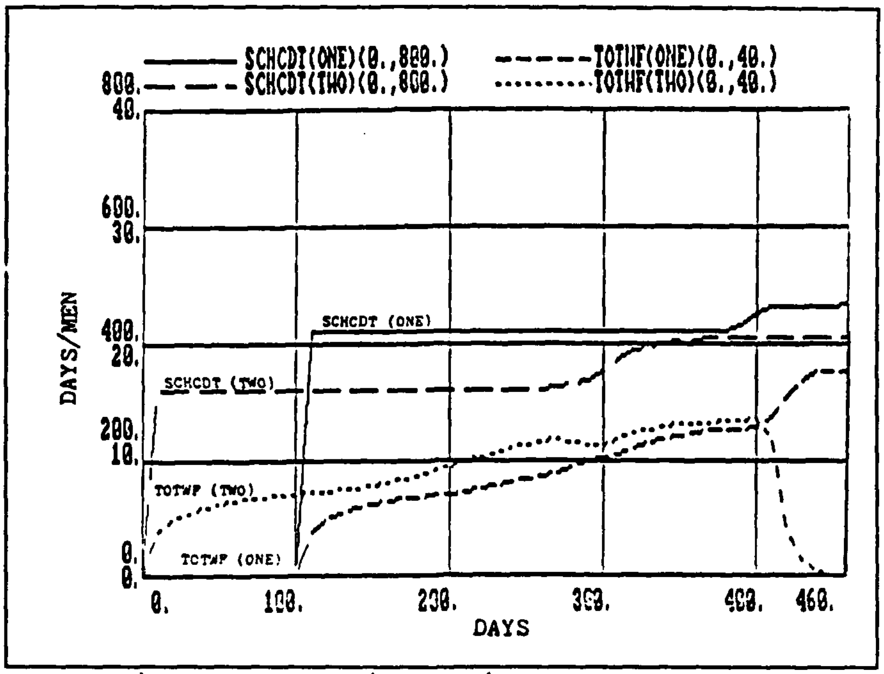


Figure 97. Simulation 13--Graph 1

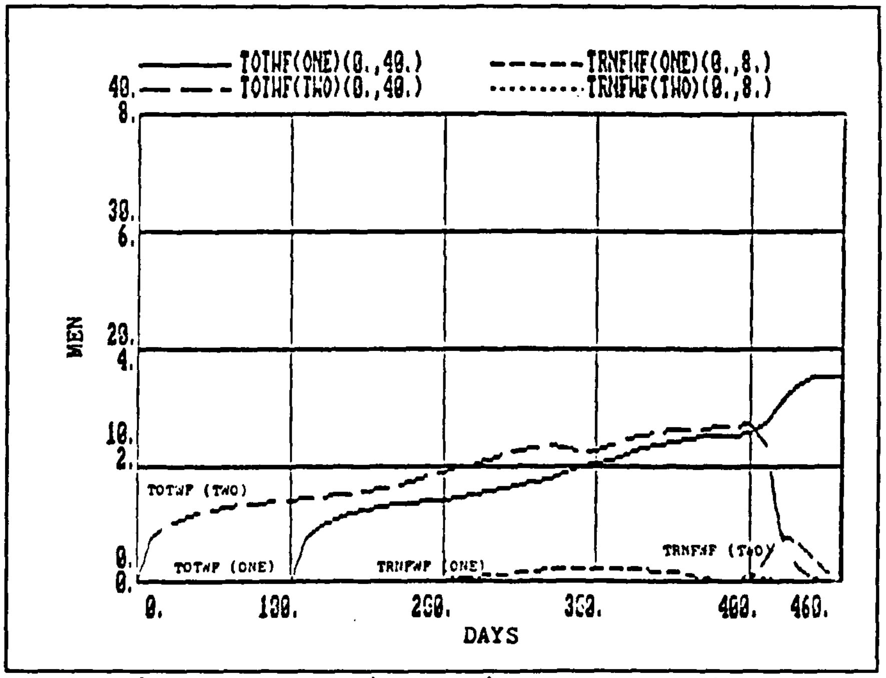


Figure 98. Simulation 13--Graph 2

14. Summary

One of the simulations of interest in experiment set three is simulation four in which the workforce ceiling allocation policy is changed from 50:50 to one in which the project with priority, project one, is able to hire up to the workforce ceiling. Project two can only hire if project one's hiring does not reach the ceiling. This simulation is of interest when compared to its equivalent in experiment set two in which costs skyrocketed when this variable was changed. This does not happen in experiment set three. The explanation for this is that in experiment set three, project two has started first with project one starting at time 100. Until project one starts, project two is able to acquire and assimilate new workers early in its development. This leads to increased productivity over the life of project two. The result of this increased productivity is less difference in cost between this simulation and the baseline than was seen in experiment set two.

This type of analysis, in which results of simulations are compared across experiment sets, is one area which warrants more attention. Also of import is analysis of the results within this experiment set. The analysis will provide more understanding of the complex and interrelated variables affecting software project management.

V. CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

A. CONCLUSIONS

The primary objective of this thesis, to extend the System Dynamics model of software project management to a multiproject environment, has been met. The extended model includes changes which were relatively narrow in scope, such as the addition of the start date variable and the addition of arrays. It also includes major changes to the human resource management subsystem. Identification and addition of variables to reflect the considerations managers must ponder when determining how and in what numbers to transfer people as well as those variables necessary to maintain organizational balance provided insight into the mechanisms of human resource management. Chapter III is devoted to an explanation of these insights. Work in this area provided the information identified under the second of the three items listed in the "Thesis Objectives" section in Chapter II.

The first item identified in that list, that of gleaning information on the effects of management manpower decisions on the allocation of resources to different projects, was addressed in the experiment sets described in Chapter IV. It becomes obvious that the way in which manpower is allocated within an organization and transferred between

projects impacts greatly on the combined cost of the projects. The experiments run with, for example, changes to the nominal ceiling on the workforce (NCLTWF) and to the workforce ceiling allocation policy (POLCY1) illustrate this point.

The last item listed in Chapter II was that of gaining insights on optimizing the staffing function in a multiproject environment. Again, the experiment sets presented in Chapter IV, particularly the first set, provide information in this area. Of interest is the fact that how priority is set, dynamically or statically, and what project has priority affects the optimal overlap to minimize cost. There is no one optimal overlap for all situations--it is dependent on the various factors relevant to any software development situation. Comparison of the results in experiment set two and three and comparisons between the two experiment sets also provide insight into optimizing the staffing function. Of interest in regard to optimization of the staff function are those variables which, when changed, cause little or no change in the cost of the projects. This result indicates that those variables, such as hiring and transferring aggressiveness (TAGRSV) in experiment set two, do not affect costs and should therefore not be an item of concern to managers.

B. SUGGESTIONS FOR FURTHER RESEARCH

This thesis provides a starting point for further research areas in several arenas. One of those is development of an expert system to automatically provide the manager with the optimal overlap to minimize cost given a certain scenario. The results presented in experiment set one were manually attained--a process no software project manager would have the time or inclination to undertake.

Another area for further research is expansion of this new model to model environments in which more than two projects are underway. Though much of the initial work in that realm has been completed in this thesis, the real possibility of the identification of other variables affecting manpower decisions in this type of environment exists.

Perhaps the most interesting area of further research in this arena is analysis of the results presented in this thesis. Of particular interest are the effects of changing the workforce ceiling and the effects of changing the hiring and transfer aggressiveness in experiment set one. In experiment set two, the cause of the drastic increase in cost when the workforce allocation policy is changed is an area for detailed analysis. The lack of a similar spike in experiment set three is also of interest. Discussions with software project managers and extensive research in the software project management field would be necessary to

explain and understand these results as presented in Chapter IV. This research could lead to identification of other variables of interest and further refinement of this model.

APPENDIX

SUMMARY RESULTS OF EXPERIMENT SET ONE

BASELINE SUMMARY RESULTS

Overlap	Cost Project 1	Cost Project 2	Total Cost
0	1823.02	1868.73	3691.75
20	1889.03	1872.55	3761.58
40	1930.09	1911.51	3841.60
60	1981.93	1933.09	3915.02
80	2042.72	1940.13	3982.85
100	2028.94	1922.49	3951.43
120	2017.60	1912.12	3929.72
140	1995.47	1901.36	3896.83
160	1996.06	1934.22	3930.28
180	1851.63	1934.56	3786.19
200	1894.76	1958.21	3852.97
300	1809.83	1954.88	3764.71
400	1828.68	1954.80	3783.48

TRANSFER PRODUCTIVITY SUMMARY RESULTS

Overlap	Cost Project 1	Cost Project 2	Total Cost
0	1830.62	1875.15	3705.77
20	1925.49	1876.01	3801.50
40	1974.57	1903.59	3878.16
60	2021.36	1936.28	3957.64
80	2079.04	1950.11	4029.15
100	2070.94	1937.74	4008.68
120	2060.92	1907.59	3968.51
140	2042.19	1916.54	3958.73
160	2050.45	1929.13	3979.58
180	1854.15	1915.05	3769.20
200	1864.97	1949.45	3814.42
300	1803.54	1954.96	3758.50
400	1829.16	1954.80	3783.96

WORKFORCE CEILING SUMMARY RESULTS

Overlap	Cost Project 1	Cost Project 2	Total Cost
0	1886.37	1877.54	3763.91
20	1906.43	1896.12	3802.55
40	1944.19	1902.30	3846.49
60	1951.44	1898.79	3850.23
80	1926.71	1900.11	3826.82
100	1914.38	1903.10	3817.48
120	1914.46	1902.29	3816.75
140	1900.24	1925.89	3826.13
160	1916.09	1922.27	3838.36
180	1877.10	1919.80	3796.90
200	1833.97	1922.21	3756.18
300	1784.05	1903.45	3687.50
400	1779.82	1903.24	3683.06

WORKFORCE CEILING AND ALLOCATION SUMMARY RESULTS

Overlap	Cost Project 1	Cost Project 2	Total Cost
0	1861.66	1853.74	3715.40
20	1845.11	1862.71	3707.82
40	1865.97	1883.68	3749.65
60	1879.48	1896.63	3776.11
80	1874.08	1899.39	3773.47
100	1889.40	1910.62	3800.02
120	1897.66	1918.52	3816.18
140	1921.20	1912.20	3833.40
160	1840.53	1874.45	3714.98
180	1830.52	1891.50	3722.02
200	1842.35	1908.62	3750.97
300	1962.25	1987.12	3949.37
400	1856.66	2030.46	3887.12

HIRING AND TRANSFERRING AGGRESSIVENESS SUMMARY RESULTS

Overlap	Cost Project 1	Cost Project 2	Total Cost
0	1920.76	1904.95	3825.71
20	1944.36	1901.39	3845.75
40	2006.75	1930.78	3937.53
60	2084.35	1947.30	4031.65
80	2135.07	1955.63	4090.70
100	2116.13	1937.46	4053.59
120	2023.54	1914.06	3937.60
140	2047.54	1907.27	3954.81
160	2112.06	1901.34	4013.40
180	1876.49	1950.46	3826.95
200	1932.36	1977.71	3910.07
300	1816.91	1962.76	3779.67
400	1842.20	1962.75	3804.95

PROJECT STARTING FIRST HAS PRIORITY SUMMARY RESULTS

Overlap	Cost Project 1	Cost Project 2	Total Cost
0	1810.49	2025.21	3835.70
20	1803.50	2044.93	3848.43
40	1813.53	2107.38	3920.91
60	1829.74	2083.19	3912.93
80	1840.69	1906.84	3747.53
100	1852.70	1838.67	3691.37
120	1863.02	1827.91	3690.93
140	1885.53	1820.44	3705.97
160	1904.28	1828.84	3733.12
180	1934.56	1851.63	3786.19
200	1958.21	1894.76	3852.97
300	1954.88	1809.83	3764.71
400	1954.80	1828.68	3783.48

PROJECT STARTING LAST HAS PRIORITY SUMMARY RESULTS

Overlap	Cost Project 1	Cost Project 2	Total Cost
0	1810.49	2025.21	3835.70
20	1805.90	2013.98	3819.88
40	1825.74	2010.19	3835.93
60	1837.31	1967.22	3804.53
80	1841.82	1949.91	3791.73
100	1845.33	1944.72	3790.05
120	1859.30	1945.46	3804.76
140	1845.87	1948.48	3794.35
160	1849.84	1950.32	3800.16
180	2050.06	1909.19	3959.25
200	1958.82	1904.26	3863.08
300	1809.83	1954.88	3764.71
400	1828.68	1954.80	3783.48

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